6 ANATOMY OF PLANTS

Anatomy (Gk. *ana*– up, *tome*– cutting) is the study of internal structure of organisms. In plants, anatomy includes histology, that is, organisation and structure of tissues.

Importance of Anatomy

1. Anatomy or study of internal structure is useful in knowing the structural peculiarities of different groups of plants.
2. It indicates the structural adaptations of plants to diverse environments.
3. It provides information to functional organisation of higher plants.
4. Structural details of different organs in different groups of plants are known.
5. Anatomy is useful for knowing **homology** (phylogenetic similarity) and **analogy** (phylogenetic dissimilarity).
6. Anatomy has solved several taxonomic problems.
7. It is useful in determining the purity of articles of daily use like tea, coffee, cocoa, tobacco, vegetable dyes, spices, asafoetida, saffron, etc.
8. In **pharmacognosy** (science connected with sources, characteristics and possible medicinal uses) purity and correct identity of plant parts is established through anatomy.
9. Plywood industry depends upon the knowledge of wood anatomy.
10. Wood anatomy helps to differentiate the superior and inferior, standard and substandard or specified and unspecified woods.
11. Forensic science employs plant anatomy for identifying pieces of plant matter sticking to dead bodies and articles used by criminals.

TISSUES

A group of cells having a common origin and co-operating with one another to perform a similar function (or a set of similar functions) *is described as a tissue*. Plasmodesmata often occur amongst cells for proper coordination. Depending upon the constitution of cells, the tissues are of two types, **simple** and **complex**. A **simple tissue** is made up of **similar cells** which carry out the same function. A **complex tissue** is made up of **two** or **more than two** types of cells which are aggregated from the beginning and perform a similar function.

Based on the capacity to divide, the plant tissues have been classified into two fundamental types, **meristematic** and **permanent**.

Meristematic Tissues

A **meristem** or **meristematic tissue** (Gk. *meristos*— divided) is a simple tissue composed of a group of **similar** and **immature cells** (*meristematic cells*) which can **divide** and form **new cells**.

Characteristics of Meristematic Cells. (i) Ability to grow and divide. (ii) Small immature cells. (iii) Isodiametric, rounded, oval or polygonal. (iv) Absence of intercellular spaces. (v) Walls are thin, elastic and made of cellulose. (vi) Nucleus conspicuous. (vii) Cytoplasm dense. (viii) Vacuoles absent or very small. (ix) Crystals absent. (x) Endoplasmic reticulum small. (xi) Proplastids are present instead of plastids. (xii) Mitochondria have simple structure. (xiii) Rate of respiration is

very high. (xiv) There is large scale synthetic activity. (xv) There is little reserve food. (xvi) Cells of the cambium are, however, slightly different. They possess large vacuoles and are elongated.

Promeristem (Gk. *pro*— before, *meristos*–divided). It is part of apical meristem having actively dividing cells and their most recent derivatives.

On the basis of plane of division, meristems are of three types— mass, plate and rib meristems.

Mass Meristem. All the cells of the body are meristematic and divide in different planes, *e.g.*, early embryo.

Plate Meristem. A flat meristem where cells divide anticlinally in two planes as during formation of leaves.

Rib Meristem (File Meristem). Meristem with only anticlinal divisions or division perpendicular to longitudinal axis in one plane.

Promeristem Derivatives. They differentiate into three regions. Hanstein (1870) has called them **histogens** (Gk. *histos*–tissue, *gennaein* — to produce). **Histogens** are tissue producing definite zones or regions. They are dermatogen, periblem and plerome.

(i) **Dermatogen.** (Gk. *derma*-skin, *genea*-birth). It is the region or histogen of single layer of outermost cells formed from the apical meristem. Dermatogen gives rise to epidermis of stem and other aerial parts. In root it gives rise to epiblema and root cap or **calyptrogen** (Gk. *kalyptra*–covering, *gennaein*–to produce). Calyptrogen is meristematic and forms root cap.

(ii) **Periblem** (Gk. *peri*–around, *blema*–covering). It is middle histogen which forms cortex of stem and roots.

(iii) **Plerome** (Gk. *pleroma*–a filling). It is the central histogen which forms stele or part of stem and root inner to endodermis. Part of plerome that forms vascular tissues is called procambium.

Haberlandt (1914) has proposed a different nomenclature of protoderm, ground meristem and procambium.

(a) **Protoderm** (Gk. *protos*–first, *derma*–skin). It is the outer layer of apical meristem that gives rise to epidermis of stem and epiblema of root.

(b) **Ground Meristem.** It is primary meristem formed from apical meristem which gives rise to ground tissues of the plant body. Ground tissues comprise all tissues except epidermis and vascular strands.

(c) **Procambium** (L. *pro*–before, *cambium*–change). It is part of meristem which gives rise to vascular tissues.

The meristematic cells are **parent cells** from which all other types of cells are formed. Depending upon their origin, meristems are of two types, **primary** and **secondary**.

1. **Primary Meristems.** They are those meristematic tissues which are derived directly from the meristems of the embryo. Depending upon their position, primary meristems are of three types : apical, intercalary and lateral (Fig. 6.1).

(a) **Apical Meristems.** The apical meristems are present at the tips of stem, root and their branches. They produce growth in length.

Vegetative Shoot Apex (Shoot Apical Meristem). It is derived from meristem present in plumule of embryo. Shoot apex occurs at the tip of stem and its branches as **terminal bud**. It also occurs in the inactive state in the axils of leaves as **lateral buds**. Shoot apex is conical or dome-shaped in outline. It is covered over and protected by means of young leaves formed by it. The meristem consists of a single apical cell in many pteridophytes. In seed plants the apical meristem is a dome-shaped mass of meristematic cells. Leaf primordia are produced periodically on the

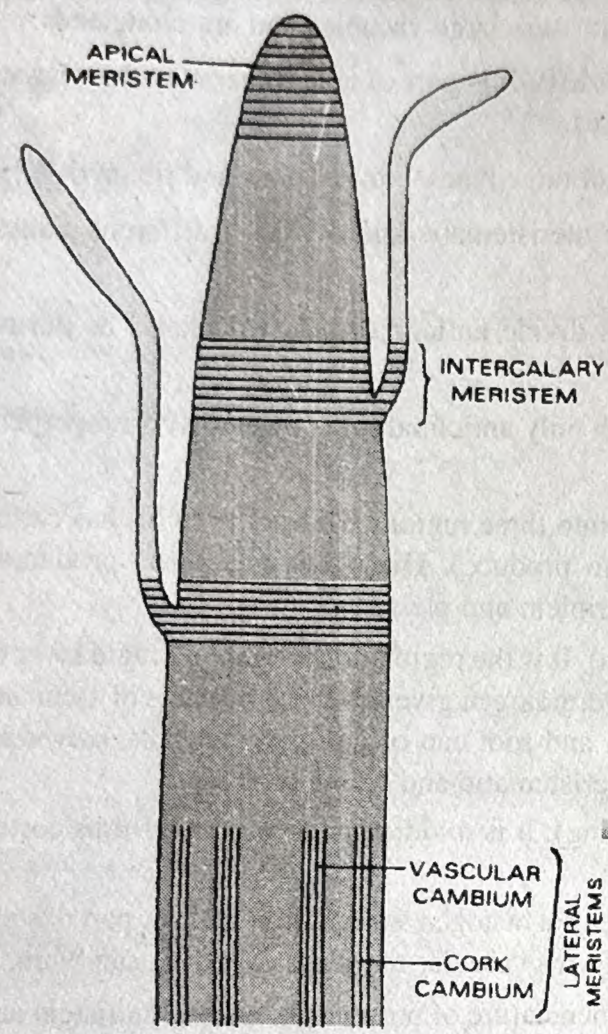


Fig. 6.1. Types of meristems.

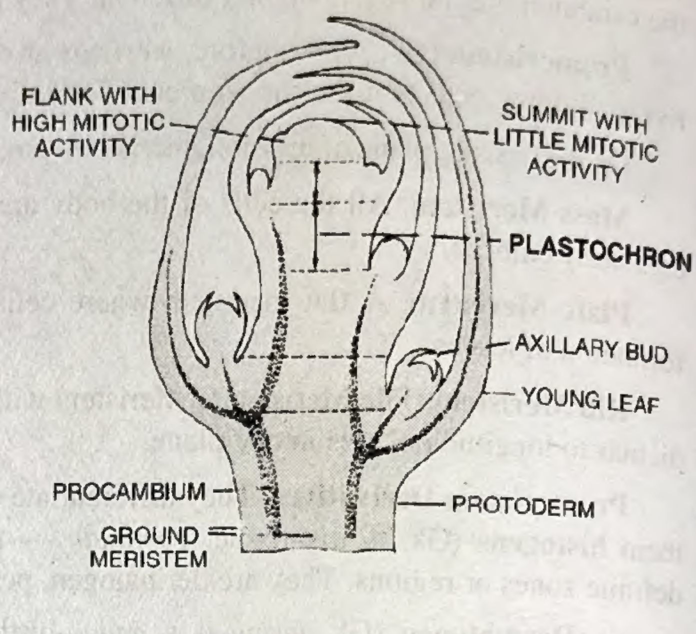


Fig. 6.2. L.S. Vegetative shoot apex showing regions of activity.

flanks. The period between the appearance of two successive leaf primordia is called **plastochron** (= plastochrone, Fig. 6.2). During a plastochron the shoot apex goes through a cycle of changes. It gives rise to derivatives in the basal region as well. They add new tissues and cause elongation of shoot. Some cells of shoot apical meristem are left behind during the formation of leaves and elongation of the stem. They consititue **axillary buds.**

Derivatives of apical meristem produce the **primary plant body.** Specific regions of apical meristem give rise to specific tissues-dermal, ground and vascular. According to **tunica-corpus** theory of Schmidt (1924), the shoot apex has two parts, outer mantle like **tunica** and inner cellular mass known as **corpus** (Fig. 6.3). Cells of tunica are small. They undergo anticlinal divisions and form surface meristem called **protoderm**. Protoderm gives rise to epidermis of both stem as well as leaves. If tunica is more than one layer in thickness, the outer layer differentiates into protoderm while the inner layers contribute to the formation of leaf interior and cortical tissues.

Cells of corpus are comparatively larger. They divide in different planes. Cells derived from corpus form procambium and ground meristem. **Procambium** is slow to differentiate. Initially its cells are narrow, elongated and densely cytoplasmic. They occur in parallel files. Procambium gives rise to primary phloem, primary xylem and intrafascicular cambium between the two (in case of dicots and gymnosperms). **Ground meristem** differentiates into pith in the centre and pericycle, endodermis, cortex and hypodermis respectively towards the outer side.

According to **histogen theory** of Hanstein (Hanstein, 1870), the stem apical meristem is differentiated into three regions or histogens (Fig. 6.4) — **dermatogen** (forms epidermis), **periblem** (forms cortex and endodermis) and **plerome** (forms pericycle, vascular bundles, medullary rays and pith).

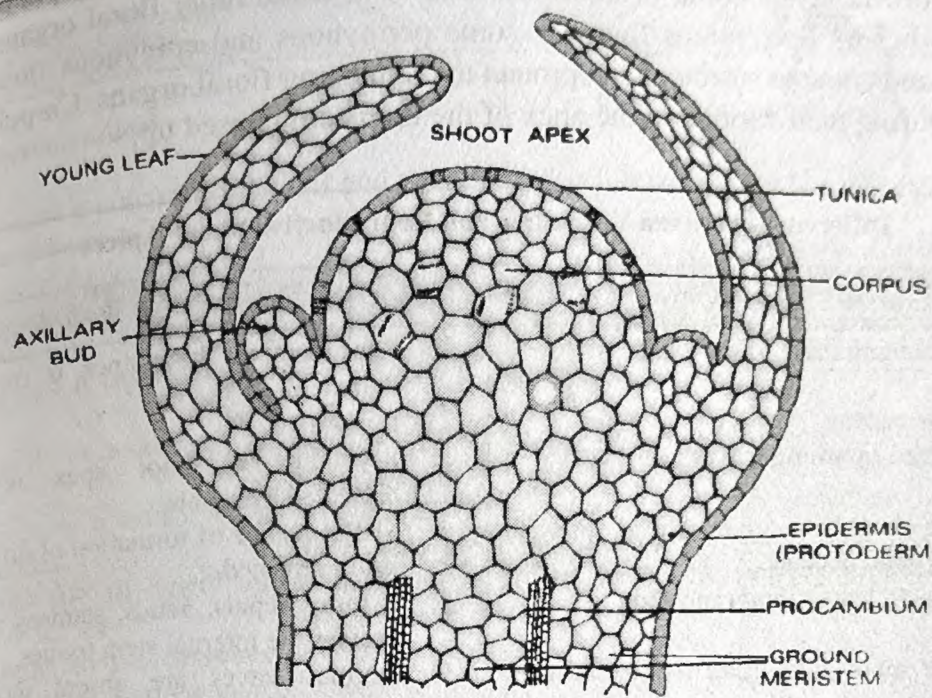


Fig. 6.3. Longitudinal section of a vegetative shoot apex.

Reproductive Shoot Apex (Fig. 6.5) During reproductive phase all or some of shoot apices get changed into reproductive apices. The shoot apex stops producing new leaf primordia and axillary buds on the flanks. The cyclicity of divisions comes to an end. The meristem broadens, becomes less conical and increases in size. The summit cells, which were quite inactive in the vegetative shoot apex, begin to divide actively. Therefore, all parts of the reproductive shoot apex show meristematic activity. It may give rise to an inflorescence or a single flower. When a single flower is to be formed, the meristematic cells give rise to different floral parts in the different regions. The meristematic cells get depleted or consumed in the formation of the various floral parts. So further growth stops. The different floral parts formed by reproductive apex from

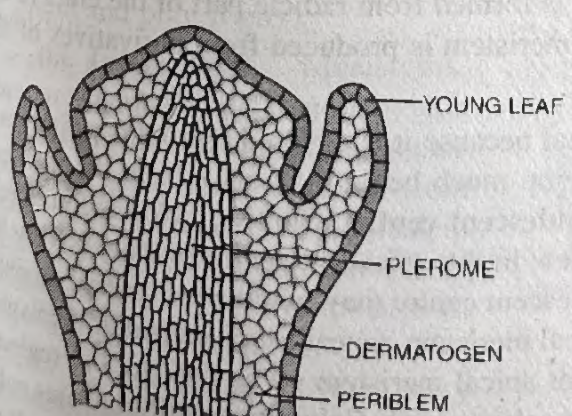


Fig. 6.4. L.S. Vegetative shoot apex showing histogens.

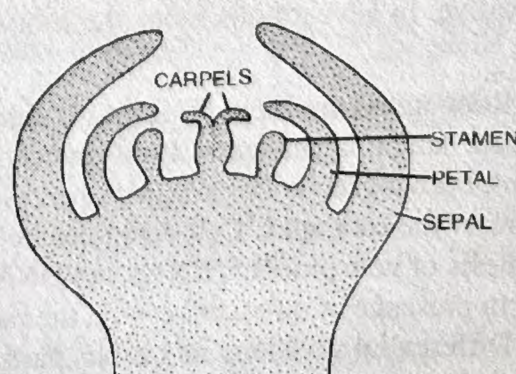


Fig. 6.5. L.S. Reproductive apex (diagrammatic).

below to tip or outside to the centre are sepals, petals, stamens and carpels. Sepal primordia are the first to be formed. They come to lie at the lower end while other floral organs are formed successively higher up (exceptions found in some perigynous and epigynous flowers). Sepals enlarge rapidly and come to surround and protect the remaining floral organs. Carpels are the last to be formed. During their formation the apex of the meristem is used up.

Differences between Vegetative and Reproductive Shoot Apices

Vegetative Shoot Apex	*Reproductive Shoot Apex*
1. It is conical in outline.	1. Reproductive shoot apex is comparatively flattened.
2. The apex is narrow.	2. It is wide.
3. It is protected by young leaves.	3. Reproductive shoot apex is generally protected by sepals.
4. Vegetative shoot apex gives rise to various parts in a cyclic manner.	4. The sequence of formation of different parts is not repeated.
5. It gives rise to leaves, buds and stem tissues.	5. It forms sepals, petals, stamens and carpels besides the internal stem tissues.
6. Vegetative shoot apex gives rise to normal leaves.	6. Normal leaves are absent though small specialized leaves called bracts can be formed.
7. Internodes are of equal length.	7. The first internode is usually very long and forms the pedicel. The other internodes are short and commonly indistinguishable. As a result the various floral whorls develop close together.
8. Lateral appendages are generally borne in spirals.	8. Lateral appendages generally develop in whorls.
9. The summit of the vegetative shoot apex is comparatively inactive.	9. The summit of the reproductive shoot apex shows active divisions.
10. Vegetative shoot apex shows indefinite growth.	10. Growth of the reproductive apex is definite or determinate.
11. The meristem is not consumed in the formation of vegetative organs.	11. The reproductive shoot apex gets consumed in the formation of reproductive organs.

Root Apex (Root Apical Meristem). It is found at the tip of main root and its branches. In case of tap root system, the root apical meristem is formed from radicle part of the embryo or its derivative. In adventitious roots, the root apical meristem is produced from derivatives of shoot apex.

Root apical meristem (Fig. 6.6) is subterminal because it is covered by root cap. It does not produce lateral appendages. Root branches develop much behind the apex from the interior of the root (endogenous origin). In many cases, a **quiescent centre** (Clowes, 1961) is found in the centre of the root apex. Cell divisions are very few in the quiescent centre as there is very little synthesis of new proteins, RNAs and DNA. Quiescent centre may function as reserve meristem. Due to presence of quiescent centre, the root apical meristem appears cup–shaped or hemispherical. Differential divisions in various parts of root apical meristem gives rise to 3–4 regions—**protoderm, procambium, ground meristem** and **calyptrogen**. Calyptrogen differentiates only in monocots. It gives rise to root cap. Protoderm forms epiblema or epidermis. In dicots it also produces root cap. Procambium gives rise to vascular tissues. Ground meristem forms pith (if present), endodermis and cortex.

Differences between Shoot Apex and Root Apex

Shoot Apex	*Root Apex*
Position	
1. It is truely terminal.	1. Root apex is actually subterminal.
Structure	
2. Shoot apex is comparatively long and spread over a distance of over 1 cm.	2. It is quite short, less than 1 mm in length.
3. It is dome-shaped in outline.	3. Root apex is generally cup-shaped in outline.
4. A quiescent centre is not distinguishable.	4. A quiescent centre occurs in many root apices.
5. Shoot apex is covered by juvenile leaves.	5. Root apex is protected by a root cap.
Function	
6. New cells are added only towards the base.	6. New cells are added both towards the base and apex.
7. It produces alternate bands of nodes and internodes.	7. Nodes and internodes are not formed.
8. It gives rise to lateral appendages in the form of leaves.	8. Lateral appendages are not produced by the root apex.
9. Primordia of the branches develop in the axils of leaves in the region of apex.	9. Primordia of branches develop far behind the root apex.
10. Branches arise exogenously.	10. Branches develop endogenously.
11. Plastochrons or periodic cyclic changes occur on the flanks of the shoot apex.	11. They are not distinguishable in the root apex.
12. Shoot apex changes its activity during reproductive phase.	12. No change occurs during reproductive phase.
13. The organization of shoot apex can be explained on the basis of tunica corpus theory.	13. The organisation of root apex can be explained on the basis of histogen theory.
14. Demarcation of the different regions of the meristem and its derivatives is not elaborate.	14. There is a high degree of differentiation in the meristem and its derivatives.

Histogen theory of Hanstein (1870) believes root apex to have three regions or histogens— **dermatogen** (forms epiblema and root cap in dicots), **periblem** (forms cortex and endodermis) and **plerome** (forms pericycle, vascular strand and pith, if any).

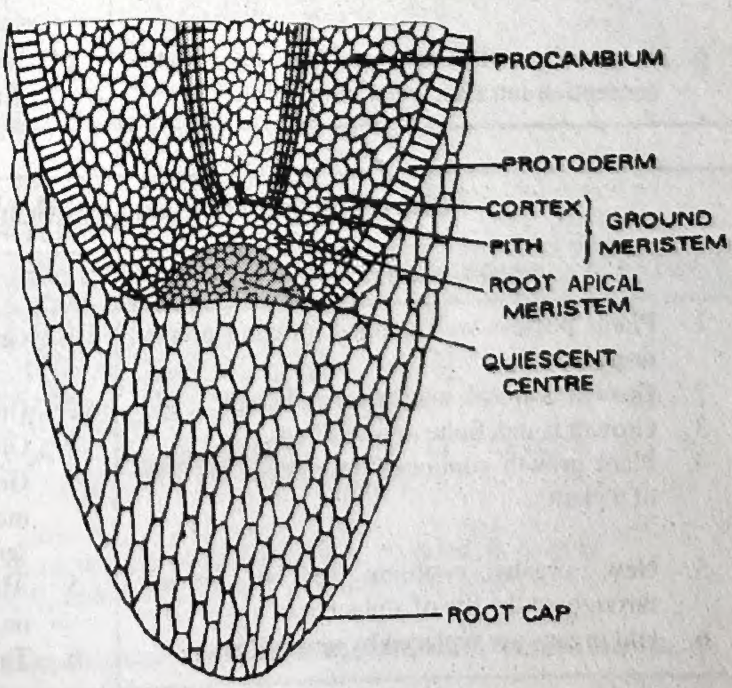


Fig. 6.6. L.S. Root Apical Meristem.

(b) **Intercalary Meristems.** They are meristematic regions which are derived from the apical meristems and which have been separated from them by the formation of permanent tissues in between. Intercalary meristems help in elongation of the organs. They also allow the fallen stems of cereals to become erect. Intercalary meristems are commonly found at the bases of leaves, above the nodes (*e.g.*, grasses) or below the nodes (*e.g.*, mint). The intercalary meristem present at the

base of *Pinus* leaf (basal meristem) lives almost throughout the life of the leaf. Usually the intercalary meristems differ from other meristems in that they ultimately get fully used up in the formation of permanent tissues.

(c) **Lateral Meristem**. The meristem occurs on the sides and takes part in increasing girth of the plant. Only one type of primary lateral meristem is found in plants. It is **intrafascicular cambium**. The cambium lies in vascular bundles of dicot and gymnosperm stems in between phloem and xylem.

2. **Secondary Meristems**. The meristems are formed secondarily from the permanent tissues. Here, some of the permanent cells acquire the power of division. The phenomenon is called **dedifferentiation**. The secondary meristems are usually lateral. They are **cylindrical meristems.** The meristems give rise to secondary tissues that constitute secondary growth. The common examples are **vascular cambium** of the root (derived from conjunctive parenchyma), **interfascicular vascular cambium** of stem (formed from medullary ray cells), **cork cambium or phellogen** (from an outer layer of cortex), **wound cambium** (from the cells surrounding an area of injury or wound) and **accessory cambia** of monocots (e.g., *Dracaena, Yucca*).

Differences between Primary and Secondary Meristems

Primary Meristem	*Secondary Meristem*
1. It is present from the beginning.	1. Secondary meristem is formed later in the life.
2. It develops from another meristem.	2. Secondary meristem develops from the permanent cells due to dedifferentiation.
3. The cells are usually isodiametric (exception intrafascicular cambium).	3. The cells are commonly elongated.
4. Central vacuoles are absent (exception intrafascicular cambium).	4. The cells possess central vacuoles.
5. It usually gives rise to primary tissues (exception intrafascicular cambium) that constitute primary growth.	5. Secondary meristem gives rise to secondary or supplementary tissues that constitute secondary growth. Secondary tissues either supplement or replace the primary tissues.
6. It usually produces growth in length (exception intrafascicular cambium).	6. Secondary meristem produces growth in thickness.

Differences between Plant Growth and Animal Growth

Plant Growth	*Animal Growth*
1. Plants possess well defined growing points or meristems.	1. Growing points or meristems are absent.
2. Growth is apical, intercalary or lateral.	2. Growth is diffused.
3. Growth is indefinite or unlimited.	3. Growth is definite or limited.
4. Plant growth continues throughout the life of a plant.	4. Growth stops in animals as soon as they mature, long before the appearance of senesence.
5. New organs continue to be formed throughout the life of a plant.	5. All organs are formed in the embryo. Later on, no new organs are added.
6. Old organs are replaced by new organs.	6. There is no such replacement.

Permanent Tissues

They are those tissues, the cells of which have lost the capacity to divide and have attained

a permanent shape, size and function due to morphological, biochemical and physiological differentiation. Depending upon their origin, permanent tissues are of two types, **primary** (derived from apical and intercalary meristem) and **secondary** (derived from a lateral meristem). On the basis of composition, permanent tissues can be simple, complex and special (*e.g.*, secretory).

Simple Permanent Tissues

A simple permanent tissue is that tissue which is made up of similar permanent cells that carry out the same function or similar set of functions. Simple permanent tissues are of three types— parenchyma, collenchyma and sclerenchyma.

Parenchyma

(Gk. *para*– beside, *engchyma*– tissue)

Parenchyma is a simple permanent living tissue which is made up of thin-walled similar isodiametric cells. It is the **most abundant** and common tissue of plants. Typically the cells are isodiametric (all sides equal). They may be oval, rounded or polygonal in outline. The cell wall is made up of **cellulose**. Cells may be closely packed or have small intercellular spaces for exchange of gases (Fig. 6.7 B). Internally each cell encloses a large central vacuole and a peripheral cytoplasm containing nucleus. The adjacent parenchyma cells are connected with one another by plasmodesmata. They, therefore, form symplasm or living continuum.

Parenchyma is morphologically and physiologically unspecialised tissue that forms the ground tissue in the non-woody or soft areas of the stems, leaves, roots, flowers, fruits, etc. The typical parenchyma is meant for the storage of food, slow conduction of various substances and for providing turgidity to the softer parts of the plants. It is modified variously to perform special functions.

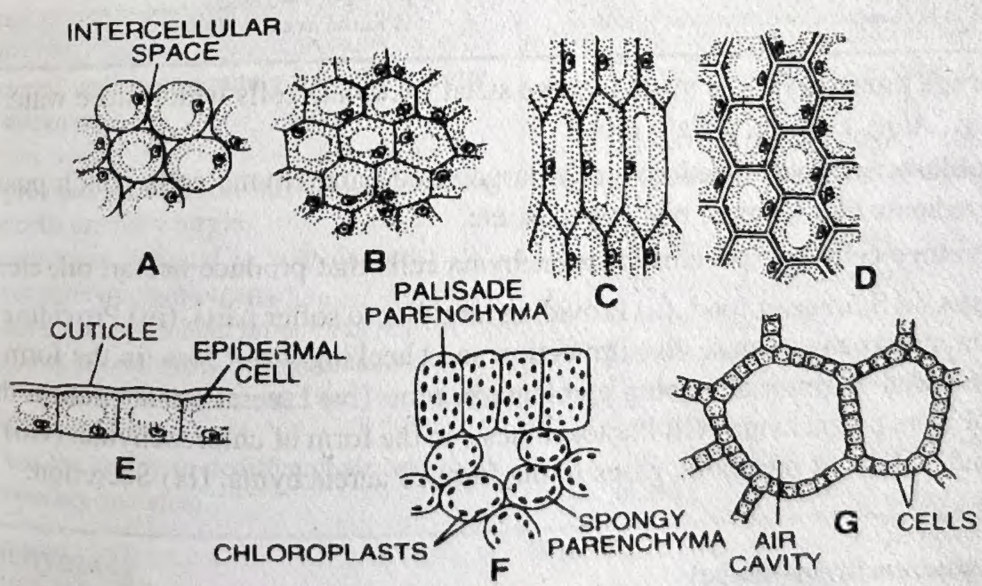


Fig. 6.7. Types of Parenchyma Cells. A–B, normal parenchyma cells; A, rounded; B, angular; C, prosenchyma; D, xylem parenchyma; E, epidermal cells; F, mesophyll; G, aerenchyma.

(a) Fibre-like elongated parenchyma is called **prosenchyma**. It is slightly thick walled and is meant for providing rigidity and strength.

(b) Cutinised parenchymatous cells form a protective covering layer or **epidermis.** Epidermis is single layered. Intercellular spaces are absent. The cutin also forms a distinct layer on the outer surface of epidermal cells. It is called **cuticle** (Fig. 6.7 E). It reduces transpiration. Epidermis may or may not bear **cutinised hair** for insulation.

(c) The young parts of the root are covered by a layer of unthickened and uncutinised parenchyma cells, some of which give rise to tubular outgrowths called root hairs. It is known as piliferous layer or **epiblema.** This layer is specialized to absorb water and mineral salts from the soil.

(d) **Xylem parenchyma** is made of small and often thickened cells. It helps in the storage of food and lateral conduction of water (Fig. 6.7 D).

(e) **Phloem parenchyma** is formed of thin-walled elongated parenchymatous cells. It takes part both in the storage and lateral conduction of food.

(f) Parenchyma cells containing chloroplasts are collectively termed as **chlorenchyma.** It takes part in the manufacture of food. Chlorenchyma of leaves is called **mesophyll.** It is differentiated into two parts, **palisade parenchyma** and **spongy parenchyma** (Fig. 6.7 F). Cells of palisade parenchyma are columnar in shape while those of spongy parenchyma are often lobed, rounded or irregular in outline.

(g) A special parenchyma tissue is found in the aquatic plants and some land plants (*e.g.*, petiole of Banana, *Canna*). It is known as **aerenchyma** (Fig. 6.7 G). It consists of a network of parenchyma cells which enclose very large **air cavities.** These air cavities store gases and make the aquatic plants light and bouyant.

Differences between Chlorenchyma and Aerenchyma

Chlorenchyma	*Aerenchyma*
1. It is parenchyma containing chloroplasts.	1. It is parenchyma containing air cavities.
2. The cells are large.	2. The cells are small.
3. It performs photosynthesis.	3. It provides buoyancy.
4. It is found in both aquatic and terrestrial plants.	4. It is found in aquatic plants.

(h) **Storage parenchyma** is made of large sized vacuolate cells which store water, mucilage and food, *e.g., Aloe, Opuntia* Potato tuber.

(i) **Idioblasts** are specialized nongreen large-sized parenchyma cells which possess inclusions or ingredients like tannins, oils, crystals, etc.

(j) **Secretory cells** are specialized parenchyma cells that produce nectar, oil, etc.

Functions. (i) Storage of food. (ii) Providing turgidity to softer parts. (iii) Providing rigidity to tissues when prosenchymatous. (iv) Protection and checking water loss in the form of epidermis. (v) Formation of water absorbing epiblema in root. (iv) Lateral conduction in the form of xylem and phloem parenchyma (vii) Photosynthesis in the form of chlorenchyma. (viii) Providing buoyancy and storage of metabolic gases in the form of aerenchyma. (ix) Secretion.

Collenchyma

(Gk. *kolla*– glue, *enchyma*– tissue)

Collenchyma is a simple permanent tissue of refractile nonlignified living cells which possess pectocellulose thickenings in specific areas of their walls. The cells appear conspicuous under the microscope due to their higher refractive index. The cells are often elongated. They are circular, oval or angular in transverse section. Internally each cell possesses a large central vacuole and a peripheral cytoplasm. Chloroplasts are often present. Wall possesses uneven longitudinal thickenings in specific areas. Depending upon the thickening, collenchyma is of three types : (i) **Angular Collenchyma.** The thickenings are present at the angles (angular

thickenings), *e.g.*, stem of Tagetes, stem of Tomato (Fig. 6.8 B). (ii) **Lamellate Collenchyma.** The thickenings occur on the tangential walls (plate thickenings), *e.g.*, stem of Sunflower (Fig. 6.8 A). (iii) **Lacunate Collenchyma.** The thickenings are found on the walls bordering intercellular spaces (lacunate thickenings), *e.g.*, *Cucurbita* stem (Fig. 6.8 C).

Collenchyma is found below the epidermis in the **petiole, leaves** and **stems** of herbaceous dicots, forming either continuous layers or occurring in patches, especially in the region of ridges (*e.g.*, Gourd).

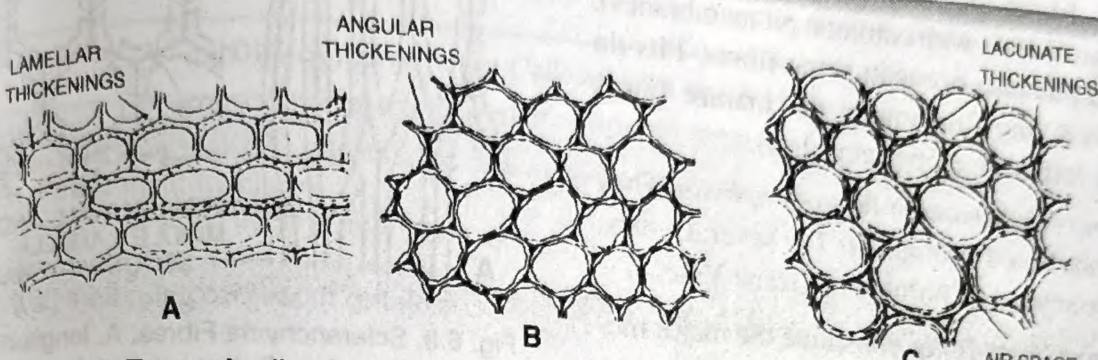


Fig. 6.8. Types of collenchyma (in T.S.). A, lamellate (plate type); B, angular; C, lacunate.

Functions. (i) It provides mechanical strength to young dicot stems, petioles and leaves. (ii) While providing mechanical strength, collenchyma also provides flexibility to the organs and allows their bending, *e.g.*, *Cucurbita* stems. (iii) It prevents tearing of leaves. (iv) Collenchyma allows growth and elongation of organs. (v) Being living, its cells store food. (vi) Its cells often contain chloroplasts and take part in photosynthesis.

Differences between Parenchyma and Collenchyma

Parenchyma	*Collenchyma*
1. The cell wall is commonly thin but uniform in thickness.	1. The cell walls develop extra thickenings at places (tangential walls, angles or adjacent to intercellular spaces).
2. It provides mechanical strength only when the cells are fully turgid.	2. Collenchyma is a living mechanical tissue.
3. Parenchyma is found in both the outer and inner parts of plant organs.	3. Collenchyma is mostly restricted to the subepidermal parts of aerial plant organs.
4. It does not have a high refractive index.	4. It usually has high refractive index.
5. It shows several types of modifications.	5. Modifications are very few.
6. It occurs in both primary and secondary structures of plants.	6. It occurs in only aerial primary body parts of the plants.
7. It has the ability to dedifferentiate and form secondary meristem.	7. The ability to dedifferentiate is nearly absent.

Sclerenchyma

(Gk. *scleros*— hard, *enchyma*— tissue)

Sclerenchyma is a simple supportive tissue of **highly** thick-walled cells with little or no protoplasm. The cell cavities are narrow. The thickening of the wall may be made up of **cellulose** or **lignin** or **both**. A few to numerous pits occur in the wall. Sclerenchyma is of two types, **sclerenchyma fibres** and **sclereids.**

* Cotton fibres are not sclerenchyma fibres but unicellular epidermal hair with secondary wall thickening of cellulose.

(a) **Sclerenchyma Fibres***. The sclerenchyma fibres are highly elongated (1–90 cm), narrow and spindle-shaped thick-walled cells with pointed or oblique end walls. The fibres generally occur in longitudinal bundles (Fig. 6.9A) where the pointed ends of adjacent fibres get interlocked to form a strengthening tissue. The adjacent fibres possess simple oblique pits (unthickened areas with common pit membranes). Bordered pits also occur in some fibres. Pits do not perform any function in the mature fibres since the latter are empty and dead.

Living firbes occur in *Tamarix aphylla*. They possess nucleated protoplasts for several years. Fibres are septate in phloem of Grape Vine.

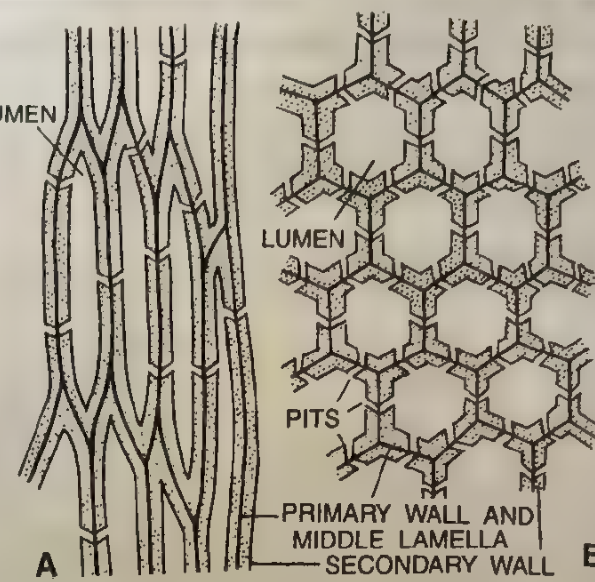


Fig. 6.9. Sclerenchyma Fibres. A, longitudinal section; B, transverse section.

Sclerenchyma fibres constitute the major mechanical tissue of the plants because they can bear compression, pull, bending and shearing. The fibres occur in all those parts where mechanical strength is required, viz., leaves, petioles, cortex, pericycle, phloem, xylem and around vascular bundles (*e.g.,* monocot stem). Commercial fibres obtained from plants are usually sclerenchyma fibres, *e.g.,* Jute, Flax, Hemp.

(b) **Sclereids**. They are highly thickened dead sclerenchyma cells with very narrow cavities. Sclereids are broader as compared to the fibres being isodiametric polyhedral, spherical, oval short or cylindrical. They may also be branched. The thick cell walls have branched or unbranched simple pits (Fig. 6.10). Being elongated, the pits of sclereids are also known as **pit canals**.

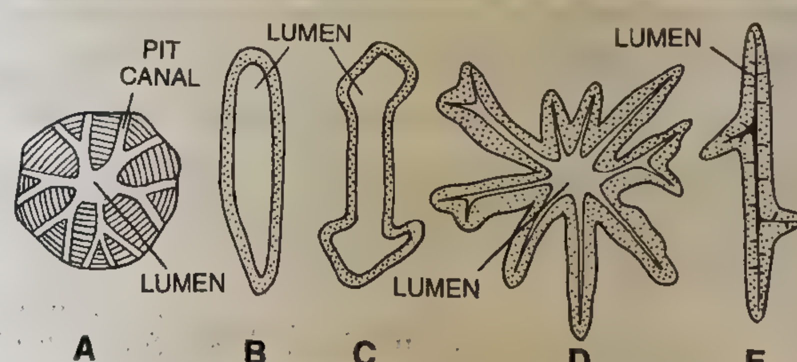


Fig. 6.10. Types of Sclereids. A, stone cell. (branchysclereid) with pit canals; B, macrosclereid; C, osteosclereid; D, astrosclereid; E, filiform sclereid.

Sclereids may occur singly or in groups. They provide **stiffness** to the parts in which they occur. The important types of sclereids are as follows :

(i) **Stone Cells** or **Brachysclereids**. Unbranched, short and isodiametric with ramiform (branched) pits, *e.g.,* grit of Guava, Sapota, Apple and Pear.

(ii) **Macrosclereids**. Elongated and columnar or rod-like, *e.g.,* epidermal covering of legume seeds.

(iii) **Osteosclereids**. Bone-like or columnar with swollen ends, *e.g.,* sub-epidermal covering of some legume seeds.

(iv) **Astrosclereids**. Branched like a star, *e.g.,* tea leaves, petiole of Lotus.

(v) **Filiform Sclereids**. Fibre-like, sparingly branched, *e.g., Olea.*

(vi) **Trichosclereids**. Very elongated hair-like and regularly once branched sclereids extending into intercellular spaces.

Functions. (i) Sclerenchyma is the chief mechanical tissue of the mature plant organs. (ii) It allows the plant organs to tolerate bending, shearing, compression and pull caused by environmental factors like wind. (iii) It provides rigidity to leaves and prevents their collapsing during temporary wilting. (iv) Sclereids provide strength to seed coverings. (v) Dehiscence of many fruits is based on differential distribution of sclerenchyma fibres, *e.g.*, pods. (vi) Sclereids form stony endocarp of many fruits called stone fruits, *e.g.*, Almond, Coconut. (vii) A number of fibres are commercially exploited, *e.g.*, Jute (*Corchorus*), Flax (*Linum*), Hemp (*Cannabis*).

Differences between Collenchyma and Sclerenchyma

Collenchyma	*Sclerenchyma*
1. It is made up of living cells.	1. Sclerenchyma cells are generally dead.
2. The cells are filled up with protoplasm.	2. The cells are empty.
3. Wall thickening is not uniform.	3. Wall thickening is uniform.
4. Wall thickening consists of cellulose.	4. Wall thickening can be of cellulose lignin or both.
5. Lumen or cell cavity is wide.	5. Lumen or cell cavity is usually narrow.
6. Pits are simple and straight.	6. Pits are usually simple and oblique. They may be branched.
7. Collenchyma provides mechanical strength as well as elasticity.	7. It is only a mechanical tissue.
8. It allows plant organs to stretch and elongate.	8. Sclerenchyma occurs in areas which have stopped elongation.
9. It keeps the organ soft.	9. It provides hardness to the region where it occurs.
10. Collenchyma has a high refractive index.	10. Refractive index is comparatively low.
11. Being living the cells can store food and take part in photosynthesis.	11. Sclerenchyma has no such function.

Differences between Fibres and Sclereids

Fibre	*Sclereid*
1. Elongated and narrow like a thread.	1. Usually broad.
2. End walls are tapering.	2. End walls are blunt in unbranched sclereids.
3. Fibres generally occur in bundles.	3. Sclereids occur singly or in loose groups.
4. Usually unbranched.	4. May be branched.
5. Pits narrow and unbranched.	5. Pits deep and commonly branched.
6. Pits are oblique.	6. Pits are straight.
7. Fibres are formed directly from derivatives of meristematic cells.	7. Sclereids arise by secondary thickening of parenchyma cells.
8. Fibres provide mechanical strength.	8. Sclereids provide stiffness only.

Complex Permanent Tissues

They are permanent tissues which contain more than one type of cells. All the types of cells of a complex tissue **work** as a unit. The common complex permanent tissues are **conducting tissues**, phloem and xylem.

Differences between Meristematic and Permanent Tissues

Meristematic Tissue	*Permanent Tissue*
1. It is a simple tissue.	1. It can be simple or complex.
2. The cells are small and isodiametric.	2. The cells are large and of different shapes according to the type of tissue.
3. Vacuoles are either small or absent.	3. Living cells of permanent tissues usually possess central vacuole.
4. Crystals and other cell inclusions are absent.	4. Crystals and other cell inclusions are often present.
5. Respiratory and biosynthetic activities are very high.	5. Both of them are at low level.
6. Intercellular spaces are very small or absent.	6. Intercellular spaces are often conspicuous.
7. The cell walls are thin.	7. The cell walls are thin or thick.
8. The cells have the property to undergo division.	8. The cells cannot normally divide.
9. The cells are immature.	9. The cells are fully differentiated.
10. Mitochondria are simple.	10. Mitochondria are fully developed.
11. Plastids are represented by proplastids.	11. Plastids are present in the living permanent cells.

Phloem

(Gk. *phlois*– inner bark; Nageli, 1858)

It is a complex tissue which **transports organic food** inside the body of the plant. Phloem is also called **bast** (= bass, a vague term). It consists of **four** types of cells, viz., **sieve tubes, companion cells, phloem parenchyma** and **fibres**. Haberlandt (1914) uses the term **leptom(e)** for the conducting part of phloem.

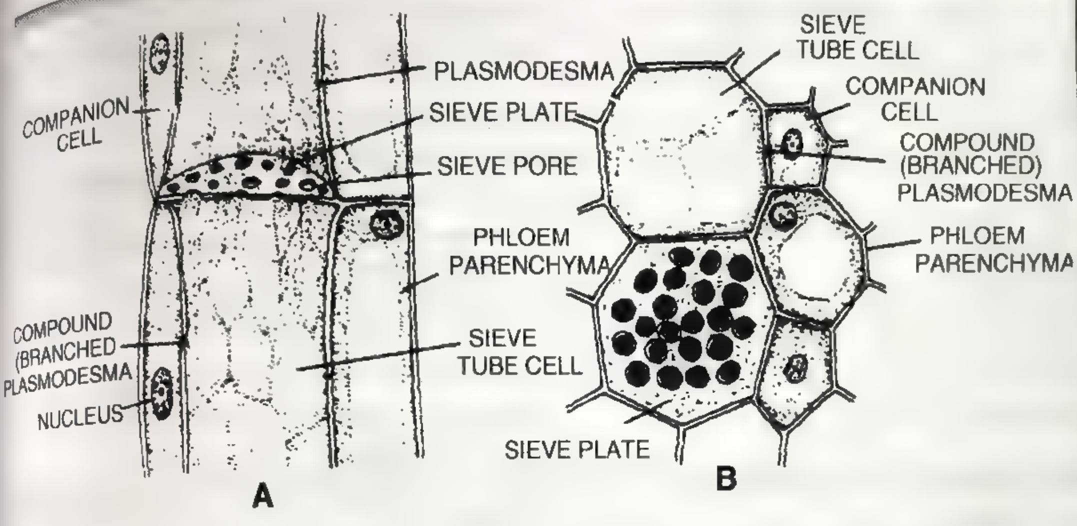
(a) **Sieve Tubes**. Sieve tubes are elongated tubular conducting channels of phloem. Each sieve tube is formed of several cells called **sieve tube elements** or **members**, sieve tube cells or **sieve elements**. Sieve tube members are placed end to end. The end walls are generally bulged out. They may be transverse or oblique. They have many small **pores** or **sieve pits**. Each sieve pore is lined by a layer of **callose**. Excessive growth of callose, however, closes the sieve pores. Due to the presence of sieve pits the end walls are commonly called **sieve plates** (Fig. 6.11 A). In some cases the end walls of sieve elements possess more than one porous area. Such an end wall is called **compound sieve plate**, *e.g.*, Grape Vine, *Euphorbia royleana*. The sieve plates connect the protoplasts of **adjacent sieve tube members.**

In non-flowering plants sieve cells remain separate. They are narrower but more elongated as compared to individual sieve tube members. The end walls are oblique. Porous areas are less conspicuous. They are borne on the lateral walls of the elongated sieve cells. They are called **sieve areas**.

Internally a sieve tube member or cell has peripheral layer of cytoplasm without any nucleus (Fig. 6.11 A). The nucleus is, however, present in the young cells. The central part is occupied by a network of canals which contain fibrils of *p*-protein. Sieve tube takes part in the **conduction of organic food**.

In temperate plants, the sieve tubes may get blocked temporarily during winter by deposition of callose over the sieve plates. The same is dissolved with the onset of spring.

(b) **Companion Cells**. Companion cells are narrow, elongated and thin walled **living cells**. They lie on the **sides** of the sieve tubes and are closely associated with them through **compound plasmodesmata**. They are squarish or rectangular in a transverse section. The cells have dense cytoplasm and a prominent nucleus. It is supposed that the nuclei of the companion cells control the activities of the sieve tube through plasmodesmata (Fig. 6.11). Companion cells also help in maintaining a proper **pressure gradient** in the sieve tube elements. Sieve tube member and its adjacent companion cells are derived from the same mother cell. Death of one results in death of the other as well. Companion cells are replaced by modified parenchyma cells (**albuminous cells**) in nonflowering plants.



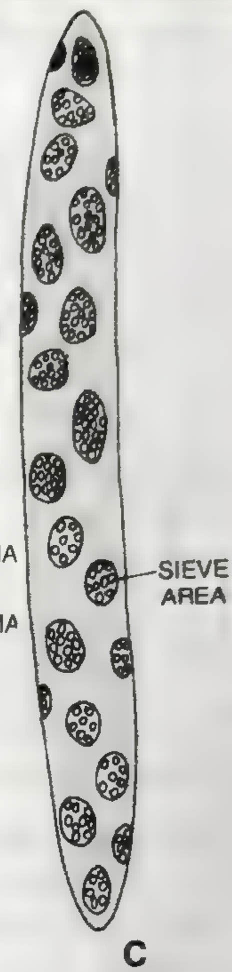


Fig. 6.11. Phloem. A, longitudinal section of phloem showing sieve tube, companion cells and phloem parenchyma cells; B, transverse section of a phloem showing sieve tube cells, companion cells and phloem parenchym cells. C, a sieve cell.

(c) **Phloem Parenchyma**. They are ordinary **living elongated** parenchyma cells having abundant plasmodesmata. They **store food**, resins, latex, mucilage, etc. The cells help in slow conduction of food, especially to the sides. Phloem parenchyma is **absent** in **most** of the monocots and some herbaceous dicots.

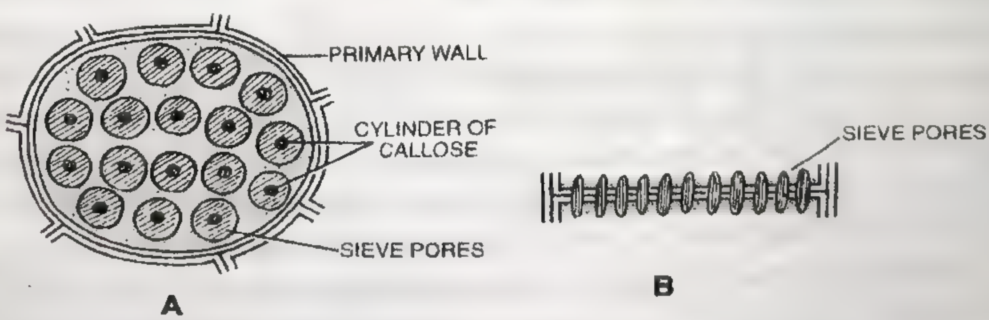


Fig. 6.12. Sieve plate. A, surface view. B, longitudinal section.

(d) **Phloem or Bast Fibres**. Sclerenchyma fibres found in the phloem are called **phloem** or **bast fibres**. They are generally absent in primary phloem but are quite common in secondary phloem where they occur more abundant in secondary phloem as compared to primary phloem. The fibres occur in sheets or cylinders. Phloem fibres provide **mechanical** strength. The textile fibres of flax, (*Linum usitatissimum*), hemp (*Cannabis*) and jute (Corchorus species) are phloem fibres.

Differences between Sieve Tube Member and Sieve Cell

Sieve Tube Member	*Sieve Cell*
1. It is a component of a long distance channel or sieve tube.	1. Sieve cell is an independently functioning entity.
2. Sieve tube members are usually associated with companion cells.	2. Companion cells are absent. Sieve cells may be associated with albuminous cells.
3. Companion cells and sieve tube elements are **sister cells** *i.e.*, derived from same mother cells.	3. Albuminous and sieve cells are derived from different mother cells.
4. The end wall is broad.	4. The end wall is pointed.
5. The pores are comparatively larger and fewer.	5. The pores are smaller but more numerous.
6. The pores or sieve pores are restricted to transverse end walls.	6. The sieve pores are found on both end walls as well as lateral walls.
7. Sieve pores generally form a single group on the sieve plate.	7. Sieve pores occur in many groups or sieve areas.
8. Sieve tube members or elements occur in flowering plants.	8. Sieve cells are found in nonflowering vascular plants (gymnosperms and pteridophytes).
9. Sieve tube elements are comparatively shorter and broader.	9. Sieve cells are comparatively narrower and longer.

Xylem

(Gk. *xylon*– wood; Nageli, 1858)

Xylem is a complex tissue which performs the function of **transport of water** or **sap** inside the plant. Simultaneously, it also provides **mechanical strength**. Xylem is also known as **wood**. It consists of **four** types of **cells**, *viz*., **tracheids, vessels** (both **tracheary elements**), **xylem** or **wood parenchyma** and **xylem** or wood **fibres**. Out of these only tracheids and vessels take part in the transport of sap. They are hence called **tracheary elements**. Vessels are the main tracheary elements of angiosperms. They are absent in gymnosperms and pteriodophytes. In the last two groups, conduction of sap is carried out by **tracheids**. The conducting elements of the xylem have been called **hadrome** by Haberlandt (1914).

(a) **Tracheids**. The tracheids are elongated (5–6 mm **dead cells** with hard **lignified walls, wide lumen** and narrow end walls. In outline they are circular, polygonal or polyhedral.The inner walls of tracheids have various types of thickenings for mechanical strength. The unthickened areas allow the rapid movement of **water** from one tracheid to another. Tracheids constitute 90–95% of wood in gymnosperms while in angiosperms they hardly form 5% of the wood. Depending upon the thickenings, tracheids are of the following types (Fig. 6.13).

(i) **Annular**. In this type the thickening material is laid down in the form of rings.

(ii) **Spiral** (Helical). The thickening is deposited like a **spiral** or helix. Both annular and spiral thickenings are present in the first formed tracheids because they allow considerable stretching.

(iii) **Reticulate**. Thickening is present in the form of a **network**. It is supposed that it is formed by the presence of several spiral bands of thickenings which cross one another.

(iv) **Scalariform**. Here the thickenings give a **ladder** like appearance because they are laid down in the form of transverse bands.

(v) **Pitted**. It is the most advanced type of thickening. The pitted tracheids are uniformly thickened except for small unthickened areas called **pits**. In surface view they may appear circular, oval or angular. Pits often occur in pairs, that is, exactly at the same level on two adjacent elements. The pits are of two types, **simple** and **bordered**. The simple pits have **uniform width** of the **pit chamber** or **cavity**. In bordered pits the pit cavity is in the form of a **flask** with a narrow aperture and a wide base. The area of the primary wall and middle lamella, which is present in a pit, is called **pit membrane** or **closing membrane**. Actually it has many submicroscopic pores for the translocation of substances. A thickening called **torus** is present on the pit membrane of some gymnosperms for protecting the membrane from rupturing in case of unequal pressure on its two sides.

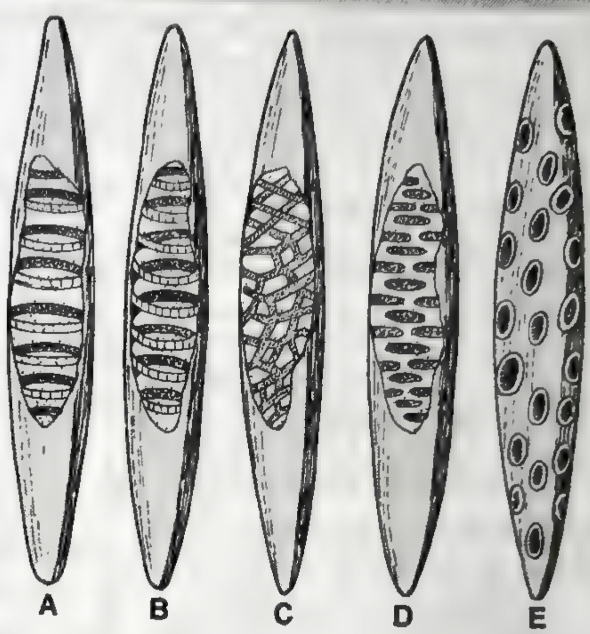


Fig. 6.13. Types of thickenings found in tracheids. A, annular; B, spiral; C, reticulate; D, scalariform; E, pitted.

(b) **Vessels**. Vessels take part, like tracheids, in the **conduction of water** or **sap** and provide **mechanical** support. They are **much elongated** tubes (3-6 metres in *Eucalyptus*) which are closed at either end and are formed by the union of several short, wide and thickened cells called **vessel elements** or **members**. The end walls of vessel elements are transverse or oblique (Fig. 6.14 B-C). They are often completely dissolved (Fig. 6.14 A). The condition is called **simple perforation plate**. In a few cases the end walls remain intact and possess several pores in reticulate, scalariform or forminate forms. Such an end wall is called **multiple perforation plate** (Fig. 6.14 D), *e.g.*, *Liriodendron*, *Magnolia*. Vessels help in quick movement of water in the plant.

The walls of the xylem vessels are **lignified**. They are thickened variously— annular, spiral, reticulate, scalariform and pitted. The pitted condition is more common. In outline the vessels are **rounded** in monocots and **angular** in dicots. Vessels are absent in gymnosperms and pteridophytes with the exceptions of a few (*e.g.*, *Selaginella* species, *Gnetum*). Their tracheary elements comprise tracheids only. Flowering plants possess both vessels and tracheids but the latter are comparatively fewer.

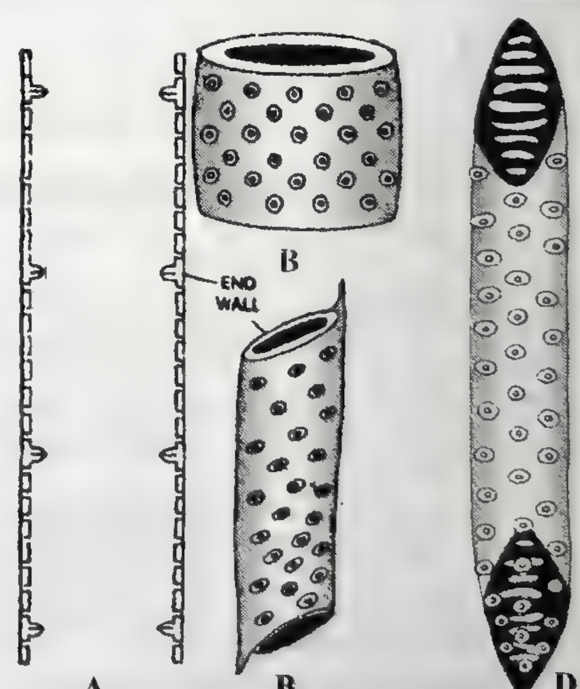


Fig. 6.14. Vessels. A, vessel in L.S. B–C, vessel elements with simple perforation plates. D, a vessel element with multiple perforation plate.

Differences between Vessels and Tracheids	
Vessels	*Tracheid*
1. A vessel is made of a number of cells.	1. A tracheid is formed from a single cell.
2. The ends are rounded or transverse.	2. The ends are generally oblique and tapering.
3. A vessel is several centimeters in length.	3. A tracheid is only a fraction of a centimeter in length.
4. The septa between adjacent cells get dissolved to produce a vessel.	4. The end walls or septa remain intact.
5. They are comparatively wider.	5. Tracheids are comparatively narrower.
6. The wall is less thickened.	6. The wall is more thickened.
7. The lumen is wide.	7. The lumen is comparatively narrower.
8. They occur in angiosperms and as occasional evolution in other vascular groups.	8. Tracheids occur in all vascular groups.

(c) **Xylem** or **Wood Parenchyma**. It is made of generally small thin or thick walled parenchymatous cells having simple pits..The wood parenchyma **stores food** (starch, fat) and sometimes tannins. It helps in the lateral conduction of water or sap. Ray parenchyma cells are specialised for this.

(d) **Xylem** or **Wood Fibres**. They are sclerenchyma fibres associated with xylem. Xylem fibres are mainly **mechanical** in function. They are **aseptate** but can be **septate**. Xylem fibres are of two types— (i) **Libriform Fibres**. Typical fibres with thick walls having simple pits and obliterated central lumens. (ii) **Fibre Tracheids**. Intermediate between fibres and tracheids having thin walls and pits with reduced borders.

Differences between Tracheid and Fibre	
Tracheid	*Fibre*
1. It is a tracheary element.	1. It is a mechanical element.
2. Tracheid is found only inside xylem.	2. Fibre occurs inside xylem, phloem, around vascular bundle, inside pericycle, cortex, hypodermis, etc.
3. It is 1–6 mm in length.	3. A fibre can be 1mm to 90 cm in length.
4. Cell wall is comparatively less thickened.	4. Cell wall is comparatively more thickened.
5. The lumen is wide.	5. The lumen is narrow.
6. Thickening can be annular, spiral, reticulate, scalariform and pitted.	6. Fibre has pitted thickening.
7. Pits are generally bordered.	7. Pits are usually simple.

Differences between Xylem and Phloem (Fig. 6.15)	
Xylem	*Phloem*
1. It conducts water or sap.	1. Phloem conducts organic food.
2. Xylem also provides mechanical strength.	2. Phloem has no mechanical function.
3. Xylem is usually found deep in the plant.	3. Phloem is usually situated towards the outer side of the plant.
4. In older plants, xylem often constitutes bulk of the plant body.	4. Phloem always forms a small part of the plant body.
5. The conducting or tracheary cells are dead.	5. The conducting cells are living.
6. Xylem is made up of three types of dead cells (vessels, tracheids, xylem fibres).	6. Phloem contains only one type of dead cells (phloem fibres).
7. There are one type of living cells (xylem parenchyma).	7. There are three types of living cells (sieve tube cells, companion cells and phloem parenchyma).

8. The conducting cells have lignin thickening in the wall.	8. Wall of the sieve tube does not possess lignin.
9. Conducting elements are of two types, vessels and tracheids.	9. Conducting elements are of one type. sieve tubes.
10. Tracheary elements have different types of wall thickenings.	10. Wall thickenings are absent in the conducting channels.
11. Vessels are devoid of septa.	11. Sieve tubes have bulging and porous septa.

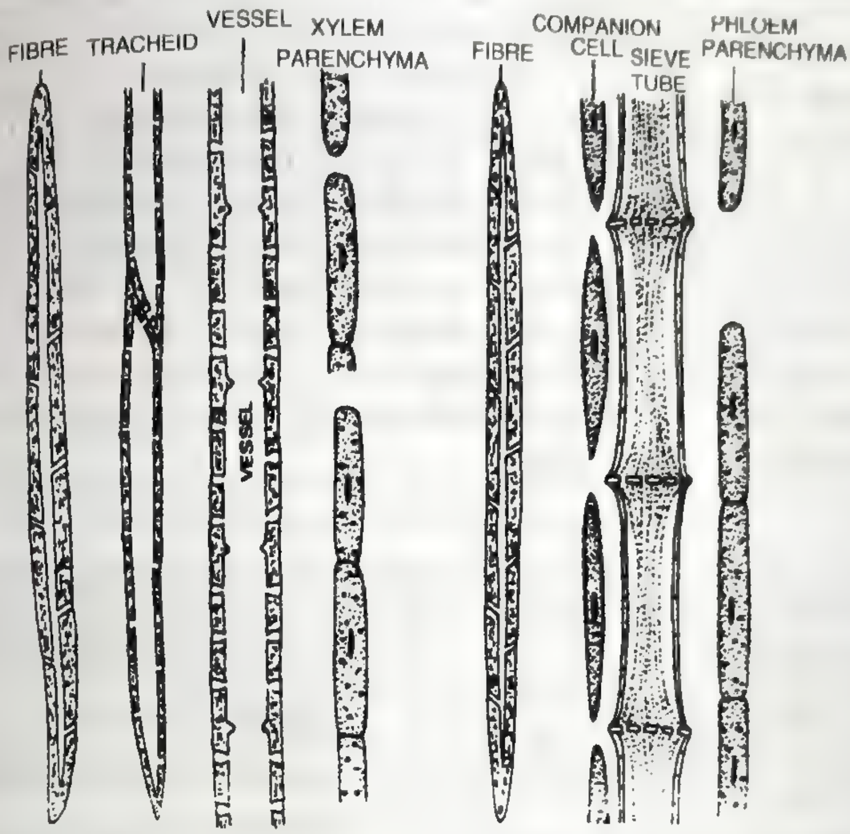


Fig. 6.15. Xylem and phloem elements.

Differences between Vessel and Sieve Tube

Vessel	*Sieve Tube*
1. It is a long distance channel for water transport.	1. Sieve tube is a long distance channel for transport of organic nutrients.
2. A vessel is made up of a large number of dead cells.	2. It is made up of number of living cells.
3. The wall is thick.	3. The wall is thin.
4 The wall possesses pits and other types of secondary thickenings.	4. Secondary thickenings are absent. Plasmodesmata occur instead.
5. The wall is lignified.	5. Lignification is absent.
6. The end walls between adjacent cells are completely dissolved.	6. The end walls are perforated with pores called sieve pits.
7. The region of end walls is not swollen or conspicuous.	7. The end walls are generally broader than the rest of the sieve tube elements.
8. In addition to transport, a vessel also helps in providing mechanical strength.	8. A sieve tube does not provide mechanical strength.

Differences between Vascular Tissues of Gymnosperms and Angiosperms	
Vascular Tissues of Gymnosperms	*Vascular Tissues of Angiosperms*
1. Xylem is devoid of vessels. 2. Phloem does not contain sieve tubes. 3. Phloem does not contain companion cells.	1. Xylem possesses vessels. 2. Sieve tubes are present. 3. Phloem possesses companion cells.

Protoxylem and Metaxylem

Depending upon the time of **origin** in relation to the growth of the plant organ, the xylem is of two types, **protoxylem** and **metaxylem**. Protoxylem (Gk. *protos*— first, *xylem*— wood) is the **first formed xylem**, where lignification begins before the completion of elongation. It is made up of small **tracheids** and **vessels** which possess annular or spiral thickenings. They are capable of being stretched. The **later formed xylem** is described as **metaxylem** (Gk. *meta*— after, *xylem*— wood). It consists of **bigger tracheids** and **vessels** which have reticulate, scalariform or pitted thickenings. Lignification occurs in them after completion of elongation. Depending upon the **position** of protoxylem in relation to metaxylem, xylem can be of four types— **exarch, mesarch, centrarch** and **endarch**. In exarch (L. *ex*— without, Gk. *arche*— beginning) type, protoxylem lies towards the **outside** of metaxylem. It is **inner** in the endarch (Gk. *endon*— within, *arche*— beginning), **middle** of metaxylem in the **mesarch** xylem (Gk. *mesos*— middle, *arche*— beginning) and centre of metaxylem in centrarch xylem.

Differences between Protoxylem and Metaxylem	
Protoxylem	*Metaxylem*
1. It is the first formed xylem.	1. It is the later formed xylem.
2. It develops before the plant organ has completed its growth.	2. It differentiates when the plant organ has completed its growth.
3. Protoxylem is comparatively less prominent.	3. Metaxylem is quite prominent.
4. It is made up of smaller and narrower elements.	4. Metaxylem is formed of broader and larger elements.
5. The wall thickenings of the conducting elements are of simple and primitive type– annular or spiral.	5. The wall thickenings are of complex and advanced type– reticulate, scalariform or pitted.
6. Lignification occurs in protoxylem elements before the completion of elongation of the plants.	6. Lignification occurs after the completion of elongation in the plant part.
7. Protoxylem elements are capable of being stretched.	7. Metaxylem elements cannot be stretched.
8. In many monocots, protoxylem elements get crushed during growth and the area comes to have a cavity.	8. Metaxylem does not get crushed.
9. Fibres are absent or rare.	9. Fibres often occur in metaxylem.

Differences between Exarch and Endarch Xylem	
Exarch Xylem	*Endarch Xylem*
1. Protoxylem is towards the outer side of the organ.	1. Protoxylem is towards the centre of the organ.
2. Exarch condition of xylem is found in roots.	2. Endarch condition of xylem is found in stems.
3. Exarch xylem occurs in radial bundles.	3. Endarch xylem is component of collateral bundles.

Protophloem and Metaphloem

Protophloem is the first formed part of phloem which develops in parts that are undergoing enlargement. It consists of narrow enucleate sieve elements which may occur singly or in groups amongst cells that often grow later into fibres. Companion cells may or may not be associated with protophloem. During elongation the protophloem elements (sieve elements) get stretched and become nonfunctional.

Metaphloem is part of primary phloem that differentiates in plant organs after they have stopped enlargement. The sieve elements are wider and longer. Companion cells are regularly associated. Fibres are absent but parenchyma cells may later become sclerified.

Differences between Protophloem and Metaphloem

Protophloem	*Metaphloem*
1. It is the first formed phloem when the plant organ is growing.	1. It is the later formed phloem which differentiates when the plant organ has completed its growth.
2. Protophloem is comparatively less prominent.	2. Metaphloem is quite prominent.
3. It is made up of smaller and narrower elements.	3. It is made up of longer and broader elements.
4. Sieve areas or pores are not prominent.	4. Sieve areas or sieve pores are quite prominent.
5. Companion cells are often absent.	5. Companion cells or their equivalents are usually present.
6. Protophloem is short lived and gets crushed.	6. It is long-lived but can be crushed during secondary growth.
7. In the region of crushed protophloem, fibres often develop from specialized cells.	7. Fibres may be present but specialized cells do not occur.

TISSUE SYSTEMS

Tissue system is a tissue or a group of tissues derived from a portion of meristem which performs a similar function in the plant body irrespective of its position. On the basis of their location and structure, Sachs (1875) recognises three tissue systems in plants— epidermal, ground and vascular.

Epidermal Tissue System

This tissue system forms the outermost covering of plant body. It is derived from protoderm. It consists of **epidermis** and **epidermal appendages.** Epidermis is made of epidermal cells and stomata.

1. **Epidermis** (Gk. *epi*— upon, *derma*— skin). Epidermis is the outermost protective layer of primary plant body. It is usually single layered. Multilayered epidermis occurs in the leaves of some tropical plants (*e.g.*, Oleander, Banyan) and aerial roots of orchids. Epidermis is a conspicuous layer of elongated, compactly arranged living cells which do not enclose intercellular spaces. The cells possess large central vacuoles and thin peripheral cytoplasm. They remain thin walled in roots and plants growing under moist conditions. The root epidermis is also called **piliferous layer** because it bears root hairs. Epidermal cells of the aerial parts of the plants have wavy lateral walls in dicots and straight walls in monocots. Their outer walls are cutinised. Cutin is a fatty-waxy substance. The cutinised walls are less permeable to water. The impermeability depends upon the thickness of cutin. Cutin also forms a separate layer on the outside of epidermis. It is called **cuticle.** Under extremely dry conditions the cuticle is reinforced by a layer of **wax**. Wax produces mealy coating or **bloom**. Wax is also present on the upper surface of floating leaves. It protects the floating leaves from wetting. In cereals the epidermal cells have a deposition of **silica**. Silica provides stiffness. It is also abrasive and hence protective against grazing.

The epidermis of aerial parts usually bears a number of minute pores called **stomata**. Stomata are absent in the surface layer of roots. They are fewer in case of stems but are abundant in case of leaves. Each stoma (singular of stomata) or stomate is surrounded by a pair of specialised epidermal cells called **guard cells**. Guard cells differ from rest of the cells in shape, size and thickenings. They also have a few small chloroplasts. The guard cells are generally bean or kidney shaped in most plants. They are dumb-bell shaped in grasses. Inner walls of the guard cells (towards the stamatal pore) are thick while the outer ones are thin. Stomata regulate transpiration and gaseous exchange with the help of their guard cells. The latter expand and contract in response to their turgidity and thus open or close the stomatal aperture.

In some cases the guard cells are surrounded or overtopped by another category of less modified epidermal cells called **subsidiary cells**. When subsidiary cells lie above the guard cells, the stomata are called **sunken**. Stomatal aperture, guard cells and subsidiary cells together constitute a complex called **stomatal apparatus**.

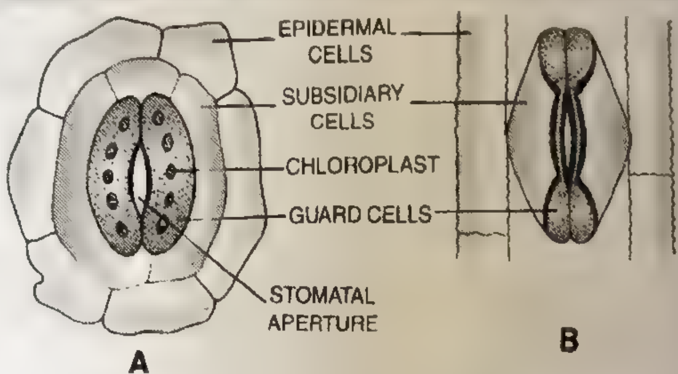


Fig. 6.16. Stomatal Apparatus. A, with bean shaped guard cells. B, with dumb-bell shaped guard cells.

In dorsiventral leaves the stomata occur mostly on the lower surface (hypostomatic) but in vertically oriented leaves and the plants growing in moist environment, they occur on both upper and lower sides (amphistomatic). In floating leaves of aquatic plants, they are restricted to the upper surface only (epistomatic).

2. **Epidermal Appendages**. They are of two types, trichomes and emergences.

Trichomes. They are unicellular or multicellular outgrowths which are strictly epidermal in origin. Trichomes are of two kinds, **hair** and **scales**. Hairs are elongated structures and can be unicellular or multicellular. Scales are multicellular flattened structures (*e.g.*, *Nepenthes*)

(i) **Root Hairs** (Fig. 6.17A) They are unicellular tubular structures found in epiblema of root in a special area called root hair zone. Root hairs are actually not appendages or protubrances but are simply enlargements of epiblema cells. Root hair cells have vacuolated protoplasm. Nucleus occurs towards the apical part of the hair. Wall is thin and pectocellulosic. Root hairs are ephemeral. New root hairs are continuously developed on young parts of the root. Root hairs take part in absorption of water and mineral salts. They also hold the soil particles and play an important role in anchoring the plant.

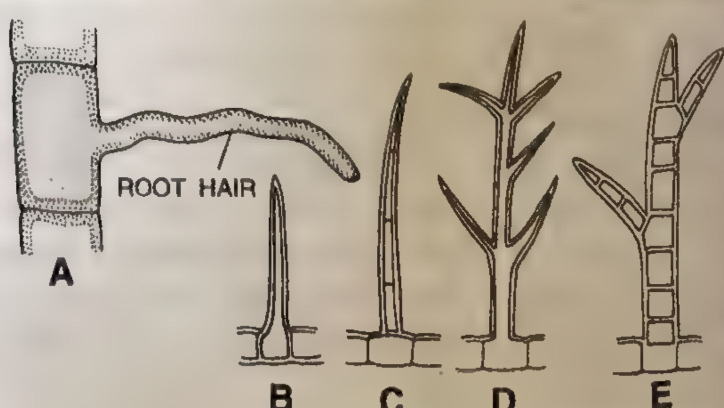


Fig. 6.17. Hair. A, root hair; B, unicellular unbranched hair of aerial surface. C, a multicellular hair of aerial surface. D, branched unicellular hair. E, branched multicellular hair.

(ii) **Aerial Hairs** (Fig. 6.17 B–E). They are unicellular or multicellular appendages which are covered by a layer of cuticle. Unicellular hairs are simple and often unbranched. Multicellular hair are more abundant. They can be unbranched or branched. The hair enclose stationary air and protect the plant organs against sudden changes

of temperature and high rate of transpiration. Cotton is obtained from long unicellular epidermal hair or **lint** (*c.f.*, fuzz) of *Gossypium* seeds. A single seed may have upto 1000 lint hair (Fig. 6.18). One kg of cotton contains over 200 million hair. The hair have cellulose thickening.

(iii) **Stinging Hairs**. They are hollow hairs that contain siliceous tips and enclose a poison which is injected into the skin of animals rubbing against them, *e.g., Urtica dioica* (Fig. 6.19 B, Stinging Nettle).

(iv) **Glandular Hairs**. Most of the glandular trichomes produce essential oils (Fig. 6.19 A). They provide characteristic odour to plants, *e.g., Citrus*, Mint. The digestive glands of insectivorous plants are also trichome in nature.

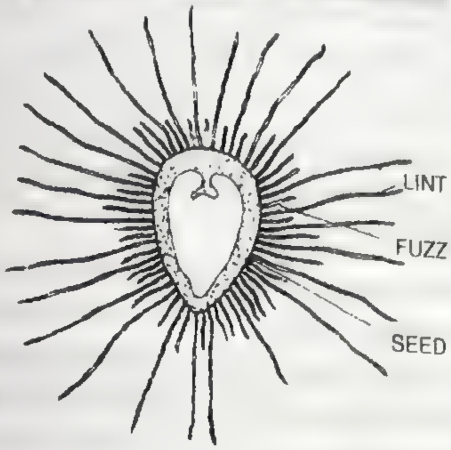


Fig. 6.18. Cotton seed with lint and fuzz hair.

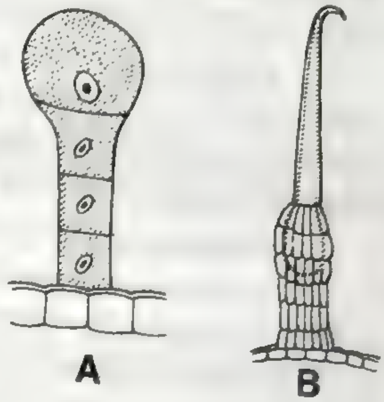


Fig. 6.19. A, gland hair of Citrus. B, stinging hair of Nettle.

Emergences. They are multicellular epidermal outgrowths which also contain some inner tissues. **Prickles** are an example of emergences. They are sharp and stiff outgrowths. Prickles do not have vascular supply. They protect the plant from excessive transpiration, grazing animals and in some roses help the plants in climbing.

Functions – (i) Being the outermost layer, it is protective in nature. (ii) It forms water and mineral absorptive system of the root. (iii) With the help of cuticle it checks the rate of water loss from aerial parts. (iv) Presence of epidermal hair form an insulating layer over the surface. (v) Prickles and stinging hair protect the plant from herbivores. (vi) Glandular hairs provide aroma to the plants. (vii) Stomata take part in exchange of gases and transpiration. (viii) Trichomes present on the surface of some seeds and fruits help in their dispersal.

Ground Tissue System

The system is formed from ground meristem or partly plerome and partly periblem that forms the interior of plant organs with the exclusion of epidermal and vascular systems. It consists of simple permanent tissues like parenchyma, collenchyma and sclerenchyma. Ground tissue system of leaves is called **mesophyll**. Mesophyll is made up of two types of photosynthetic cells, **palisade** and **spongy**. Palisade parenchyma occurs towards the upper surface. It is formed of columnar cells. Abundant chloroplasts occur in these cells. Intercellular spaces are quite narrow. Spongy parenchyma occurs towards the lower epidermis and encloses large intercellular spaces. Its cells are rounded, isodiametric, angular or lobed. They contain good number of chloropolasts.

The ground system of monocot stem has two parts, hypodermis and ground parenchyma. In roots and dicot stems, the ground tissue system is differentiated into hypodermis, cortex, endodermis, pith and medullary rays. Pericycle is actually constituent of vascular tissue system but is often included in ground tissue system.

1. **Hypodermis**. It forms a few layers of collenchyma or sclerenchyma that lies below the epidermis. It provides mechanical strength and rigidity. In aerial stems it additionally functions as heat screen.

2. **Cortex**. Cortex is commonly thin-walled parenchymatous region that lies between endo-

dermis and hypodermis/epidermis. It stores food and performs some additional functions like enclosing large air cavities in aerenchyma and performing photosynthesis if chlorenchymatous. In stem the primary function of cortex is the formation of protective zone. Its secondary function is storage of food. Accessary functions include photosynthesis and retention of gases if aerenchymatous. In roots, the primary function of cortex is storage of food. In root hair zone it is transfer of absorbed water and minerals to the interior.

3. **Endodermis**. Endodermis is the innermost layer of cortex that consists of tightly packed barrel shaped cells. It is called **starch sheath** in case of dicot stems. In roots its cells possess ligno-suberin **casparian strips** or **bands**. Major function of endodermis is to act as check post between vascular strand and cortex.

4. **Pericycle**. It is the outer boundary of vascular strand that is one to several cells in thickness. In roots it gives rise to lateral branches. Part of vascular cambium is also formed by it. Pericycle of yound roots is made up of thin walled cells. In stem pericycle may be parenchymatous, sclerenchymatous or both. Sclerenchymatous pericycle is both protective and supportive. Parenchymatous pericycle helps in exchange of material between cortex and vascular bundles. Pericycle is absent in stems and roots of aquatic plants.

5. **Pith**. It lies in the centre and is often parenchymatous. It is well developed in dicot stems and monocot roots. Intercellular spaces may or may not be present. Pith is repository of many excretory substances like tannins, phenols, calcium, etc. It may also store food.

6. **Medullary Rays**. They are nonvascular areas which occur between vascular bundles in dicot stems for lateral conduction.

Vascular Tissue System

It forms a strand of vascular tissues that is known as **vascular strand** or vascular cylinder. In gymnosperms and flowering plants, the vascular tissues occur in distinct patches called **vascular bundles**. The latter are **radial** in roots and **conjoint** in case of stems and leaves (Fig. 6.20).

1. **Radial Bundles**. Here xylem and phloem occur in the form of separate bundles called **xylem bundles** and **phloem bundles**. The two types of bundles usually alternate with each other. They occur on different radii. Radial bundles are characteristic of roots.

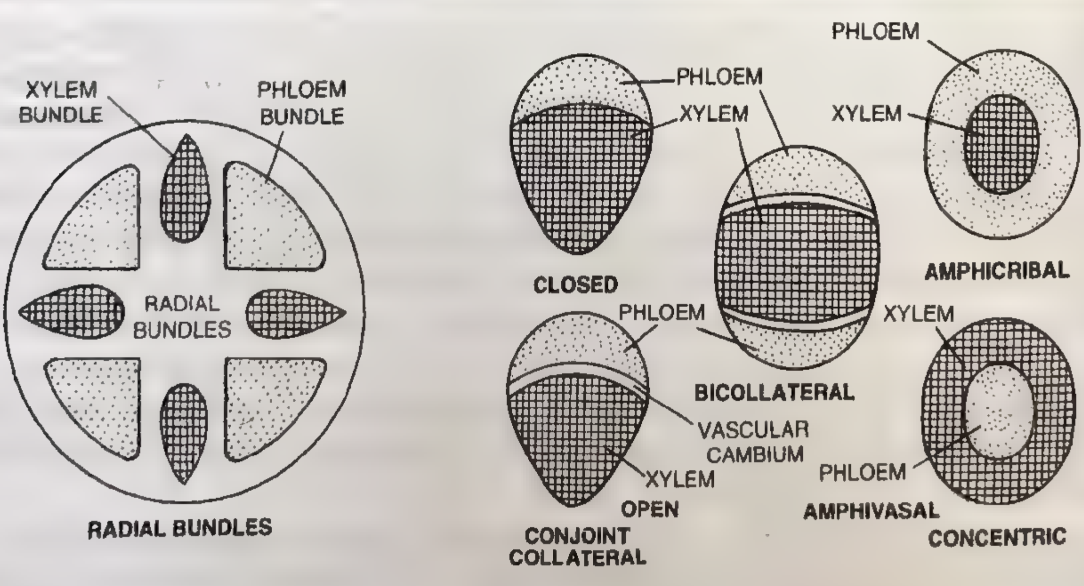


Fig. 6.20. Types of vascular bundles.

2. **Conjoint Bundles.** The vascular bundles which contain both xylem and phloem are called conjoint vascular bundles. Conjoint bundles are of the following three types.

(i) **Collateral Bundles.** They are those conjoint bundles in which phloem and xylem lie together on the same radius with phloem on the outer side and xylem towards the inner side. In gymnosperms and dicot stems a strip of vascular cambium occurs between phloem and xylem of each vascular bundle. It is called **intrafascicular** (or fascicular) **cambium**. This strip of vascular cambium later produces secondary tissues. Such vascular bundles are described as **open** because the original or primary phloem and xylem separate on the production of secondary tissues by vascular cambium. In monocot stems vascular bundles do not have a strip of vascular cambium. They are termed as **closed.**

Differences between Open and Closed Vascular Bundles

Open Vascular Bundle	*Closed Vascular Bundle*
1. Vascular bundle contains a strip of cambium in between phloem and xylem.	1. Intrafascicular cambium is absent.
2. Phloem and xylem do not lie in direct contact with each other.	2. Phloem and xylem occur in direct contact with each other.
3. Due to activity of cambium, original or primary phloem and xylem move away from each other. Secondary phloem and secondary xylem are formed in between.	3. There is no such activity.
4. Open vascular bundles occur in dicot and gymnosperm stems.	4. Closed vascular bundles are found in leaves and monocot stems.
5. Open vascular bundles can be collateral and bicollateral.	5. Closed vascular bundles can be collateral or concentric.

(ii) **Bicollateral Bundles.** Bicollateral vascular bundles have phloem both on the outer and inner side of xylem. All the three lie on the same radius. Usually a strip of vascular cambium is present on both outer and inner sides of xylem. Bicollateral bundles occur in Cucurbitaceae (*e.g.*, Pumpkin or *Cucurbita pepo*, Ridge gourd or *Luffa cylindrica*) and some members of families Solanaceae, Convolvulaceae, etc.

Differences between Collateral and Bicollateral Vascular Bundles

Collateral Bundle	*Bicollateral Bundle*
1. It contains a single patch of phloem.	1. There are two patches of phloem.
2. Phloem lies towards the outer side and xylem towards the inner side.	2. Phloem occurs both on the outer side as well as on the inner side. Xylem occupies the central position.
3. If open, a collateral bundle contains a single strip of cambium.	3. A bicollateral bundle is often open. It contains two strips of cambium, outer and inner.

(iii) **Concentric Bundles.** Here out of the two types of vascular tissues (phloem and xylem), one forms a solid core while the other surrounds it completely on all sides. A strip of vascular cambium is always absent. Concentric bundles are of two kinds:

(a) **Amphicribal (Hadrocentric) Bundle**. Xylem forms a central core while phloem surrounds it on all sides. It occurs in some aquatic angiosperms and the staminal bundles of many dicots (*e.g., Prunus*).

(b) **Amphivasal (Leptocentric) Bundle**. Phloem lies in the centre of the vascular bundle which is completely surrounded by xylem, *e.g., Dracaena, Yucca*.

ANATOMY OF DICOTYLEDONOUS AND MONOCOTYLEDONOUS PLANTS

PRIMARY DICOT ROOT (Figs. 6.21-22)

A young dicot root which possesses only primary permanent tissues derived from the apical growing point is called **primary dicot root.** It is cylindrical in outline and possesses the following tissues (Fig. 6.22).

1. **Epiblema or Piliferous Layer** (Rhizodermis). It is the outermost layer of the root. It is made of compactly arranged thin-walled flattened and slightly elongated parenchymatous cells. Epiblema of root differs from the epidermis of stem in being devoid of distinct cuticle and stomata. Some cells of the epiblema give rise to thin-walled tubular outgrowths called **root hairs.** They are called **trichoblasts**. Trichoblasts are generally smaller than other epiblema cells. The root hairs lie in between the soil particles and are in contact with the soil water. Root hairs possess a gummy pectic layer on the outside for cementing with soil particles and retaining water on the surface. Due to the presence of root hairs, the epiblema is also called **piliferous layer** (L. *pilus*— hair, *ferre*— to carry). The root hairs and thin-walled epiblema cells **absorb water** and **minerals salts** from the soil. Root hairs commonly do not live for more than one week. With their death the epiblema cells become suberised and cutinised.

Differences between Stem and Root Hairs

Stem Hairs	*Root Hairs*
1. They are generally multicellular.	1. Root hairs are unicellular.
2. Stem hairs are additional cells. They do not arise as outgrowths of the epidermal cells.	2. Root hairs are tubular outgrowths of epiblema cells.
3. They may be branched or unbranched.	3. Root hair are always unbranched.
4. They are spread all over the stem.	4. They are found in clusters in young roots near their tips. It is known as root hair zone.
5. Stem hairs are heavily cutinised.	5. Root hairs are not cutinised.
6. They are long-lived.	6. They are short lived.
7. Stem hairs prevent or reduce the rate of transpiration.	7. Root hairs take part in absorption of water from the soil.

2. **Cortex**. It lies below the epiblema. The cortex is made up of many layers of thin walled parenchyma cells. The parenchyma cells may be rounded (*e.g.*, *Cicer*) or angular (*e.g.*, Sunflower). They enclose intercellular spaces for diffusion of gases. The cells of the cortex **store food**. They also **conduct water from the epiblema to the inner tissues**.

3. **Endodermis**. Endodermis is usually considered to be the innermost layer of the cortex. It is made up of a **single** layer of barrel-shaped cells which do not enclose intercellular spaces. The cells are rich in starch grains. The young endodermal cells possess a band of thickening which runs along their radial and tangential walls. This band of thickening is called **casparian strip** (after Caspary, 1865; Fig. 6.21). It is made up of both suberin and lignin (Esau, 1965). In a transverse section, the casparian strip appears in the form of small lenticular swellings on the radial walls only. Casparian strips prevent plasmolysis of endodermal cells. Due to the presence of casparian strips, the endodermal cells do not allow wall to wall movement of substances between cortex and pericycle. Substances must enter the cytoplasm of endodermal cells. As a result, endodermis functions as a **biological check post**. All tissues on the inner side of endodermis constitute **stele.** It consists of pericycle, vascular bundles and pith.

4. **Pericycle**. Endodermis is followed by one (*e.g.*, Sunflower) or more (*e.g.*, Mulberry) layers of pericycle. Pericycle is believed to represent the outer boundary of vascular strand. The

cells of pericycle are thin-walled and parenchymatous in the young root. Pericycle is a very important layer. A part of the vascular cambium is formed by the pericycle. The cork cambium also develops from it. All lateral roots originate from the pericycle. Pericycle is absent in the roots of some aquatic plants and parasites.

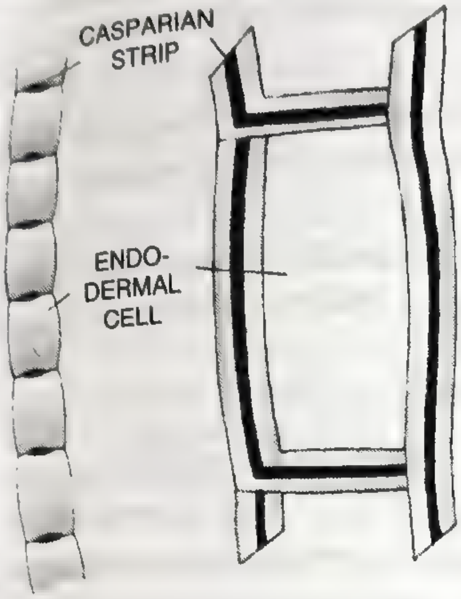


Fig. 6.21. Endodermal cells with casparian strip. A, T.S.; B, position of casparian strip in a cell.

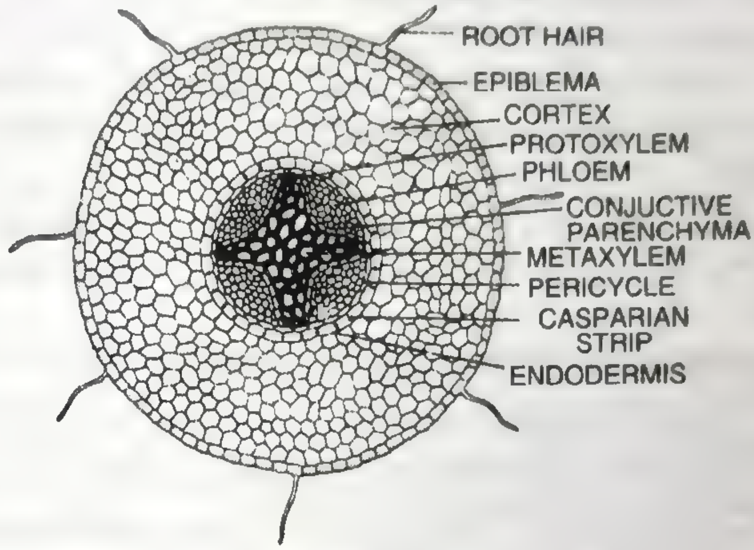


Fig. 6.22. T.S. Dicot root of Sunflower.

5. **Vascular Strand** or **Cylinder**. Inner to the pericycle are found a few (2–6) alternately arranged **bundles** of **xylem** and **phloem**. They are equal in number and lie on different radii. Such vascular bundles are called **radial bundles**.

The various **xylem bundles** put together give a stellate or star-shaped appearance. The number of rays is equivalent to the number of xylem bundles (and phloem bundles). According to the number of rays, the root may be **diarch** (with 2 xylem bundles, *e.g.*, Tomato), **triarch** (Pea), **tetrarch** (Buttercup, Gram, Sunflower, Castor), **pentarch** (with 5 xylem bundles) or **hexarch** (with 6 xylem bundles). In some cases different divisions of roots possess different number of strands, *e.g.*, two in lateral roots and four in main roots of Garden Nasturtium. Such roots are called **heteroarchis**.

Protoxylem or the first formed xylem lies in contact with pericycle and at the tip of the rays while **metaxylem** or later formed xylem is present towards the centre of the root. Such a xylem is called **exarch** (L. *ex*— outside, Gk. *arche*— beginning). The metaxylem elements of different xylem bundles may lie separate from one another so that a **pith** is present in the centre of the root (*e.g.*, Gram, Bean). However, usually the xylem bundles extend along the radii so that metaxylem elements of different bundles meet in the centre to form a solid star-shaped structure. In such a case the pith is absent.

Xylem is made up of vessels and a few tracheids. Vessels and tracheids are polygonal in outline. Protoxylem elements are fewer, **smaller** and **narrower**. The metaxylem elements are **larger** and **wider**. They have pitted thickenings while protoxylem possesses spiral, annular, reticulate or

scalariform thickenings. Xylem performs two important functions : (i) mechanical strength, (ii) conduction of water and mineral salts to the shoot.

In between the two adjacent xylem bundles is found a **phloem bundle**. It is oval in outline. Phloem and xylem bundles are separated from each other by one or more layers of small thin walled cells called **conjunctive parenchyma** or **tissue**. Later on the conjunctive tissue becomes meristematic to form **vascular cambium**.

Phloem consists of sieve tubes, companion cells and phloem parenchyma. It conducts organic food from the shoot to the root and its branches. Fibres may occur outside the phloem in some roots (*e.g.*, Gram).

Radial arrangement of vascular bundles is a mechanism to keep the xylem bundles in direct contact with the outer tissues of the root which conduct water absorbed by the root hairs to the inside.

6. **Pith**. It is often absent. When present, the pith is quite small. The latter is made of parenchyma cells. Intercellular spaces are absent. The cells store food as well as waste materials.

MONOCOT ROOT (Figs. 6.23-24)

There is no such distinction between a young and an old root of a monocotyledonous plant. This is due to the **absence of secondary growth** in the monocot roots. Typical monocot root consists of the following parts (Fig. 6.23).

1. **Epiblema** or **Piliferous Layer** (Rhizodermis). It is the outermost layer of young root which has thin-walled cells. Some of the cells give rise to root hairs. They have a gummy pectic layer on the outside for cementing with soil particles and retaining water. Root hairs are tubular in outline and lie in contact with soil water. Both epiblema and root hairs are devoid of cuticle. They take part in the absorption of water and mineral salts. In older parts the epiblema is shed or becomes impervious.

2. **Cortex**. It is very wide region of parenchyma cells that enclose intercellular spaces for the exchange of gases. The cells store food. In older roots the outer one (*e.g., Smilax*) or more (*e.g.*, Maize) layers of the cortex become thick walled and suberised. They constitute the **exodermis**. It is protective and to some extent absorptive in function.

The cortex of a monocot root has, therefore, three functions: (i) conduction of water from the root hairs to the inner tissues (ii) storage of food (iii) the outermost layer or layers of the cortex produce protective exodermis in the older roots.

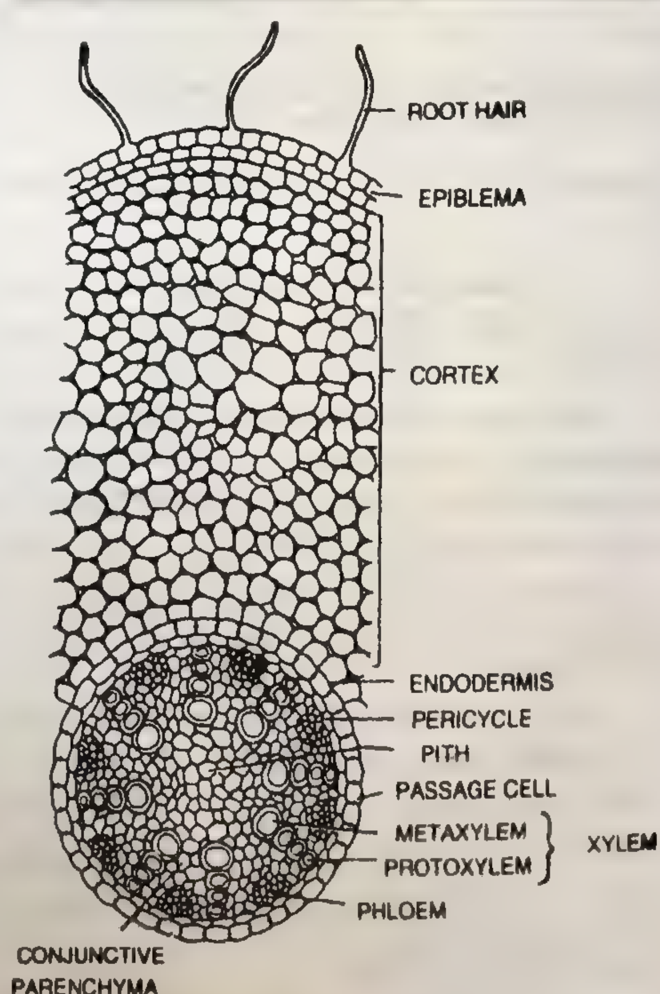


Fig. 6.23. T.S. Part of typical monocot root.

3. **Endodermis**. Endodermis or inner boundary of the cortex is single layered. It is made up of barrel-shaped cells which do not enclose intercellular spaces. The young endodermal cells possess an internal strip of suberin and lignin which is known as **casparian strip**. However, it soon becomes indistinguishable due to the additional thickening of the endodermal cells. Endodermal cells lying opposite the protoxylem groups, however, remain in the primary stage with usual casparian strip (Zeiglar *et al*, 1963). These unthickened cells are called **passage** or **transfusion cells**. The passage cells are meant for the conduction of fluids inwardly from the cortex and outwardly from the interior into the cortex. The thickened cells can also allow transport through plasmodesmata of pits (Clarkson and others, 1968).

The endodermis **regulates the flow of fluid** both inwardly as well as outwardly by functioning as biological check post.

4. **Pericycle**. Pericycle or outer boundary of vascular strand lies below the endodermis. Pericycle may be uniseriate (single layered, *e.g.*, Maize) or multiseriate (multilayered, *e.g.*, *Smilax*). In monocots the pericycle does not form cambium. It only produces lateral roots. The pericycle is composed of thin-walled parenchymatous cells in the young root. But later on it becomes thick-walled in many monocots.

5. **Vascular Strand** or **Cylinder**. It is in the form of several (8 or more) **alternate** and **radial xylem** and **phloem bundles**. The number is 20–30 in Maize and 100 or more of each type in *Pandanus* and palms. In many cases the vascular bundles are embedded in a cylinder of sclerenchymatous conjunctive tissue (*e.g.*, Maize). The vascular bundles are arranged in the form of ring around a central pith. The **xylem bundles are exarch**, *i.e.*, protoxylem lies towards the outside while the **metaxylem** faces inwards. Because of the presence of numerous xylem bundles and

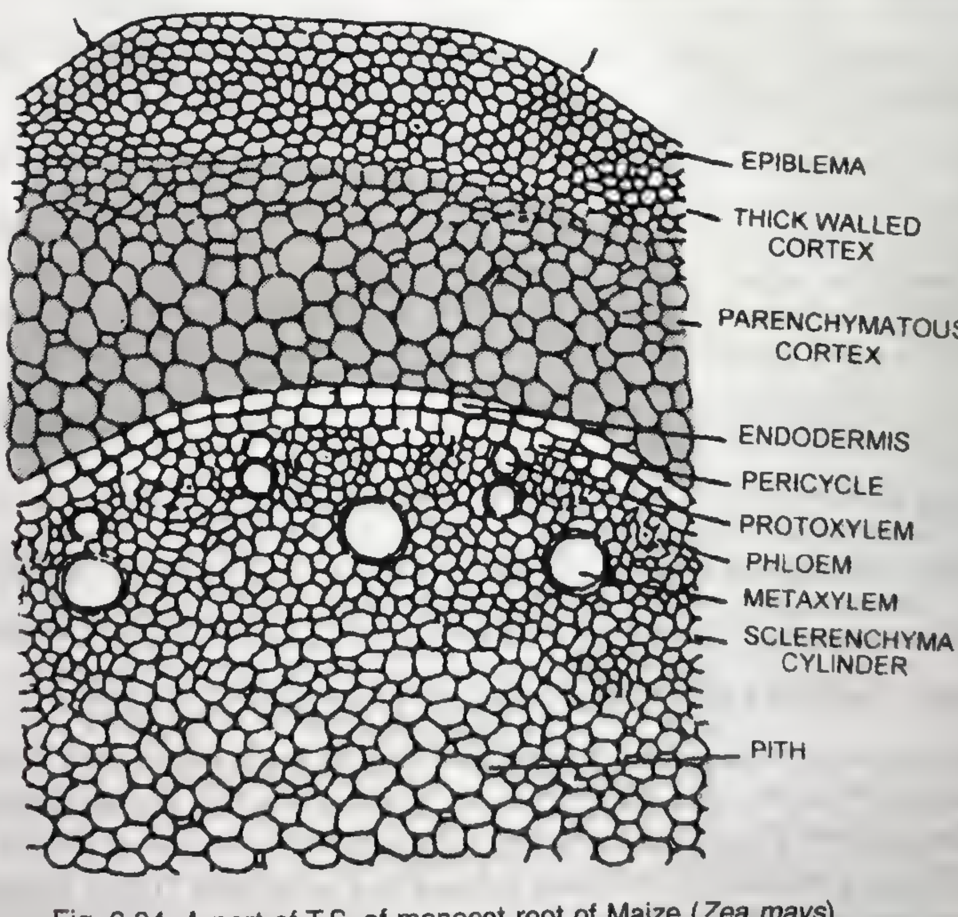


Fig. 6.24. A part of T.S. of monocot root of Maize (*Zea mays*).

exarch condition, xylem of monocot root is **polyarch**. Xylem is made up of **rounded** or **oval** vessels and xylem parenchyma. The vessels of metaxylem are larger than those of protoxylem. Protoxylem vessels are narrow. They have a spiral annular or reticular thickenings. Metaxylem vessels are broad. Usually they possess pitted thickenings. Xylem provides mechanical strength and helps in the conduction of water and mineral salts.

Phloem bundles alternate with the xylem bundles. These two are separated from each other by means of narrow strip of **conjunctive tissue**. The cells of this tissue store food if parenchymatous. They provide mechanical strength on becoming sclerified. They do not take part in the formation of cambium.

Phloem consists of sieve tubes and companion cells. It helps in the **conduction of organic** food. A distinction between protophloem and metaphloem may or may not be present.

6. **Pith**. The centre of monocot root is occupied by the pith. It consists of parenchymatous (thin-walled or thick-walled) cells which may be rounded or angular. Intercellular spaces are present amongst the pith cells. The pith cells store **food**.

Differences between Dicot and Monocot Root

Dicot Root	*Monocot Root*
1. Cortex is comparatively narrow.	1. Cortex is very wide.
2. The epiblema, the cortex and even the endodermis are peeled off and replaced by cork.	2. Cork is not formed. The cortex and the endodermis persist. Only the epiblema is peeled off.
3. Older root has a covering of cork.	3. Older root has a covering of exodermis.
4. Endodermis is less thickened and casparian strips are more prominent.	4. Casparian strips are visible only in young root. The endodermal cells later become highly thickened.
5. Passage cells are generally absent in endodermis.	5. Thin walled passage cells generally occur in the endodermis opposite the protoxylem point.
6. Pericycle produces lateral roots, cork cambium and part of the vascular cambium.	6. Pericycle produces lateral roots only.
7. The number of xylem and phloem bundles varies from 2-5 or sometimes 8.	7. Xylem and phloem bundles are numerous and are 8 or more in number.
8. Xylem vessels are generally angular.	8. Xylem vessels are oval or rounded.
9. Conjunctive tissue is parenchymatous.	9. Conjunctive tissue may be parenchymatous or sclerenchymatous.
10. Conjunctive parenchyma forms the cambium.	10. Conjunctive parenchyma does not produce cambium.
11. Secondary growth takes place with the help of vascular cambium and cork cambium.	11. Secondary growth is absent.
12. Pith is either absent or very small.	12. A well-developed pith is present in the center of the root.

SECONDARY GROWTH IN DICOT ROOT (Figs. 6.25-26)

Secondary growth is the growth in thickness due to the formation of secondary tissues by lateral meristems. With the exception of some annuals, most of the dicots and gymnosperms show secondary growth in their roots. It takes place by the production of two types of secondary tissues. They are **secondary vascular tissues** and **periderm**. These tissues are formed by meristems, **vascular cambium** and **cork cambium** respectively.

1. **Secondary Vascular Tissues. Stage I** (Fig. 6.25 B). Conjunctive parenchyma cells lying

on the inner edges of the primary phloem bundles become meristematic. They give rise to small quantity of secondary xylem on the inner side and secondary phloem on the outer side. In the process, these cambial strips and primary phloem bundles are pushed slightly to the outside. Stage II. Conjunctive parenchyma cells on the lateral sides of the phloem bundles as well as

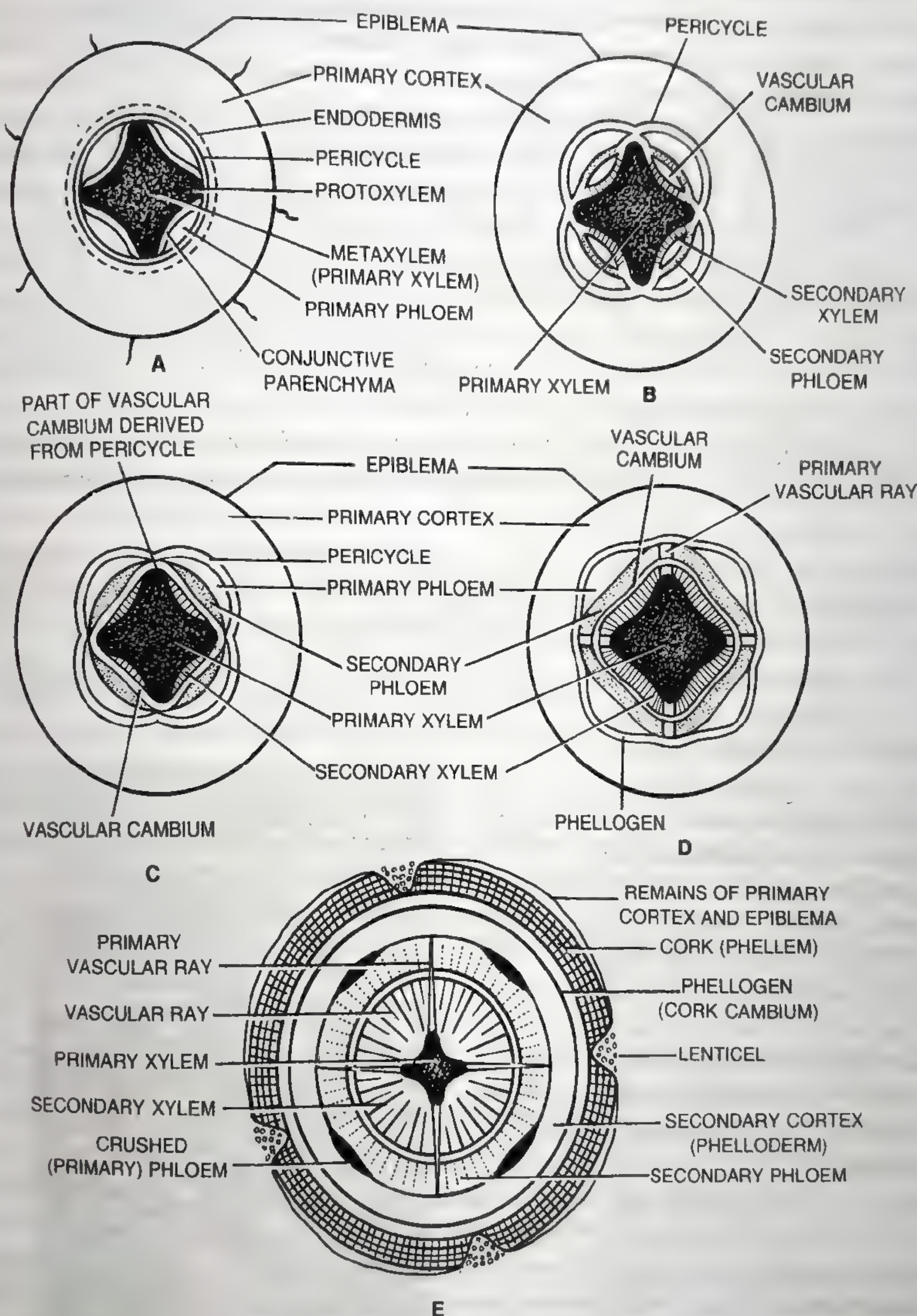


Fig. 6.25. Stages in secondary growth of a Dicot Root.
A, root with vascular strand; B, initial formation of secondary xylem and some secondary phloem and pushing out of the primary phloem; C, ring of vascular cambium completed; D, straightening of the cambial ring and formation of primary vascular rays; E, narrowing of primary vascular rays and formation of phellogen or cork cambium; completed secondary growth (diagrammatic).

pericycle cells lying outside the protoxylem ends become brick-shaped and meristematic. This gives rise to a wavy band of a vascular cambium (Fig. 6.25 C). The vascular cambium of the root is a **complete secondary meristem**. It continues to form secondary xylem on the inner side and secondary phloem on the outer side. Secondary phloem consists of sieve tubes, companion cells, phloem parenchyma and phloem fibres. Secondary xylem is similarly made of vessels, xylem parenchyma and xylem fibres. **Stage III**. Initially vascular cambium derived from the pericycle gives rise to only ray cells. Hence wide multiseriate **primary vascular rays** (also called **medullary rays**) are formed opposite the protoxylem points. However, the formation of ray cells is slower than the formation of secondary vascular tissues. As a result the depressed parts of vascular cambium move outwardly and ultimately the cambium becomes circular (Fig. 6.25 D). **Stage IV**. The **ring** of **vascular cambium** produces **secondary xylem** on the **inner** side and **secondary phloem** to the **outside**. Both of them are in the form of rings (Fig. 6.25 D-E) (*c.f.*, primary vascular bundles). The primary phloem gets crushed by the growth of secondary vascular tissues. The older secondary phloem is also partially destroyed as the new phloem becomes functional. The primary and secondary xylems persist. Primary xylem is distinguishable by its exarch nature and central position. As compared to the primary xylem, the vessels of the secondary xylem are broader and thinner. Annual rings are not very sharp because unlike aerial climate, the climate of the soil does not vary much during different seasons.

The **secondary phloem** is made up of sieve tubes, companion cells and phloem parenchyma. Sclerenchyma fibres are rare. The **secondary xylem** is formed of vessels, tracheids and xylem parenchyma.

At places the vascular cambium possesses **ray initials**. They produce **vascular rays**. The rays are made up of two parts, **xylem** or **wood ray** (present in secondary xylem) and **phloem ray** (present in secondary phloem). They help in radial conduction of substances.

2. **Secondary Ground Tissues or Periderm (Stage V)**. The pericycle layer, either directly or after a few divisions becomes converted into a secondary meristem called **cork cambium** or **phellogen** (Fig. 6.25 D-E). Rarely phellogen appears in the cortex. The cells of phellogen divide both towards the outside as well as inside. The tissue formed towards the **inner side** is parenchymatous and known as **secondary cortex** or **phelloderm**. It is only a few layers in thickness.

The cells formed on the **outside** by the phellogen are rectangular and compactly arranged. They soon become dead. Their cavities get filled up with tannin and their walls become suberised. They are described as cork cells. The tissue of cork cells is spoken

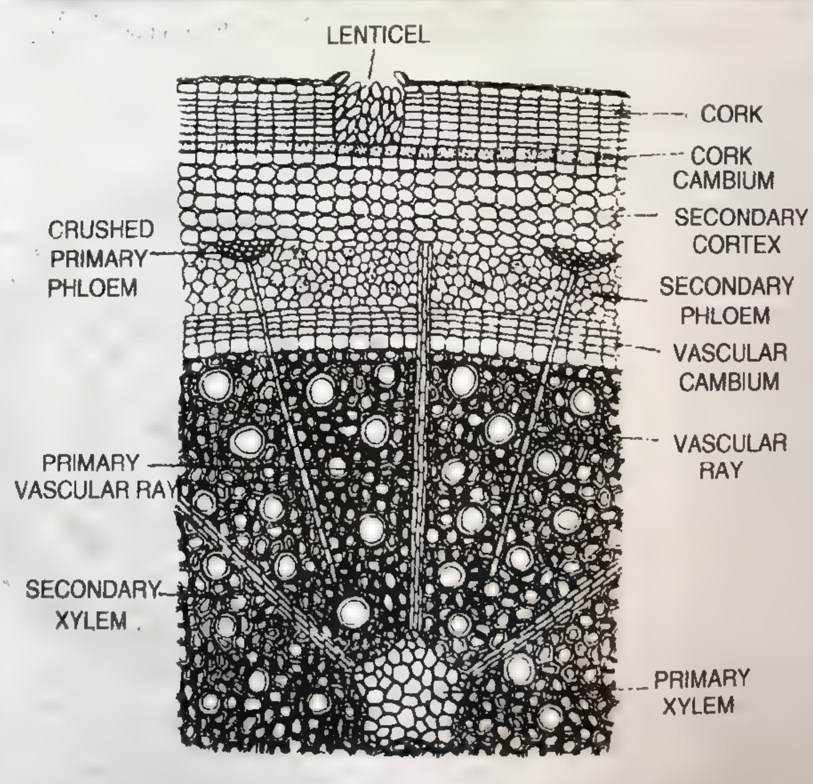


Fig. 6.26. A part of T.S. of an old dicot root showing secondary growth and a lenticel.

as **cork** or **phellem** (Fig. 6.25 F). The cork is impervious to water. It protects the interior from mechanical injury and entry of bacteria. Primary tissues present outside the cork undergo starvation and get shrivelled. Under the impact of secondary growth in the interior, the outer layers of the cork are also peeled off occasionally. The phellem, the phellogen and the phelloderm are collectively called secondary ground tissue or **periderm**. At places the phellem or cork bears **lenticels** for exchange of gases (Figs. 6.25 E, 6.26).

PRIMARY DICOT STEM (Fig. 6.27)

In outline, primary dicot stem may be circular (*e.g.*, Sunflower) or angular (*e.g.*, *Cucurbita*). The various tissues of the primary dicot stem are arranged in concentric fashion. From outside to inside they are as follows :

1. **Epidermis**. Epidermis is the **outermost** layer of the stem. It is made up of compactly arranged elongated parenchymatous cells, which look rectangular-barrel shaped in a transverse section. The cells are transparent and devoid of chloroplasts. The outer walls are convex, thickened and cutinised. On the outer side they possess a layer of **cuticle**. The internal walls of the epidermal cells are thin. The radial walls are thick towards the outer side and gradually become thin towards the inner side. Pits occur in the radial walls.

The epidermis of Sunflower stem bears several unbranched multicellular **hair** or trichomes. Like epidermis, they are covered by cuticle. At places the epidermis contains minute pores called **stomata** or **stomates**. Each stomate or stoma (sing. of stomata) has a pair of specialised **kidney shaped cells** called **guard cells**. The guard cells have a few **chloroplasts**. By their swelling, the two guard cells can form a pore in between them.

The various **functions** of the epidermis are (i) protection of internal tissues, (ii) prevention of entry of harmful organisms, (iii) minimising surface transpiration by having thick cuticle, (iv) exchange of gases through the stomata, (v) protection against excessive heating up and sudden changes in temperature with the help of hair (as in Sunflower).

The tissue between epidermis and pericycle is called **Cortex.** It has three parts—hypodermis, general cortex and endodermis.

2. **Hypodermis**. The hypodermis is made of 3–4 layered sub-epidermal **collenchyma** tissue. Its cells possess extra cellulose thickening in various regions— on the tangential walls (lamellate collenchyma, *e.g.*, Sunflower), at the angles (angular collenchyma, *e.g.*, Castor) and near the intercellular spaces (lacunate collenchyma, *e.g.*, *Cucurbita*). Collenchyma cells are green and enclose small intercellular spaces. Hypodermis functions in (i) providing mechanical strength as well as flexibility, (ii) storage of food and (iii) manufacture of food with the help of chloroplasts. Hypodermis is absent or inconspicuous below the stomata.

3. **General Cortex**. It is a few to several cells in thickness. The cortex is made up of **thin walled** angular (*e.g.*, Castor), oval or rounded (*e.g.*, Sunflower) parenchymatous cells. They enclose intercellular **spaces**. In the young green stem, the outer cortical cells possess chloroplasts (chlorenchyma) and manufacture food. However, major **function** of the cortex is **storage** of food. In Sunflower the cortex contains a number of longitudinally running **oil ducts**. Each oil duct has a channel which is lined by an epithelium of small glandular cells.

4. **Endodermis.** It is a **wavy layer** of one cell in thickness. The endodermis lies at the **innermost** boundary of cortex. It is made up of barrel-shaped cells which do not enclose intercellular spaces. Casparian strips are generally absent. The endodermal cells often contain conspicuous starch grains as food reserve. Therefore, the stem endodermis is also called **starch sheath.**

5. **Pericycle.** It is few layered thick tissue. It lies inner to endodermis and **outside** the vascular strand. The pericycle is **heterogenous.** It is made up of both parenchyma and sclerenchyma fibres. Sclerenchyma lies on the outside of vascular bundles in the form of semicircular to semilunar

patches called **bundle caps**. As the bundle caps are associated with phloem part of vascular bundles, the sclerenchymatous pericycle is also called **hard bast**. Parenchymatous pericycle is present outside medullary rays. In *Cucurbita*, pericycle is **homogeneous**. It is a completely sclerenchymatous wavy layer of 4–5 celled thickness. The sclerenchymatous pericycle provides mechanical strength to the young stem. The parenchymatous pericycle stores food.

6. **Vascular Strand**. The vascular strand is in the form of **eustele** or a **ring** of **vascular**

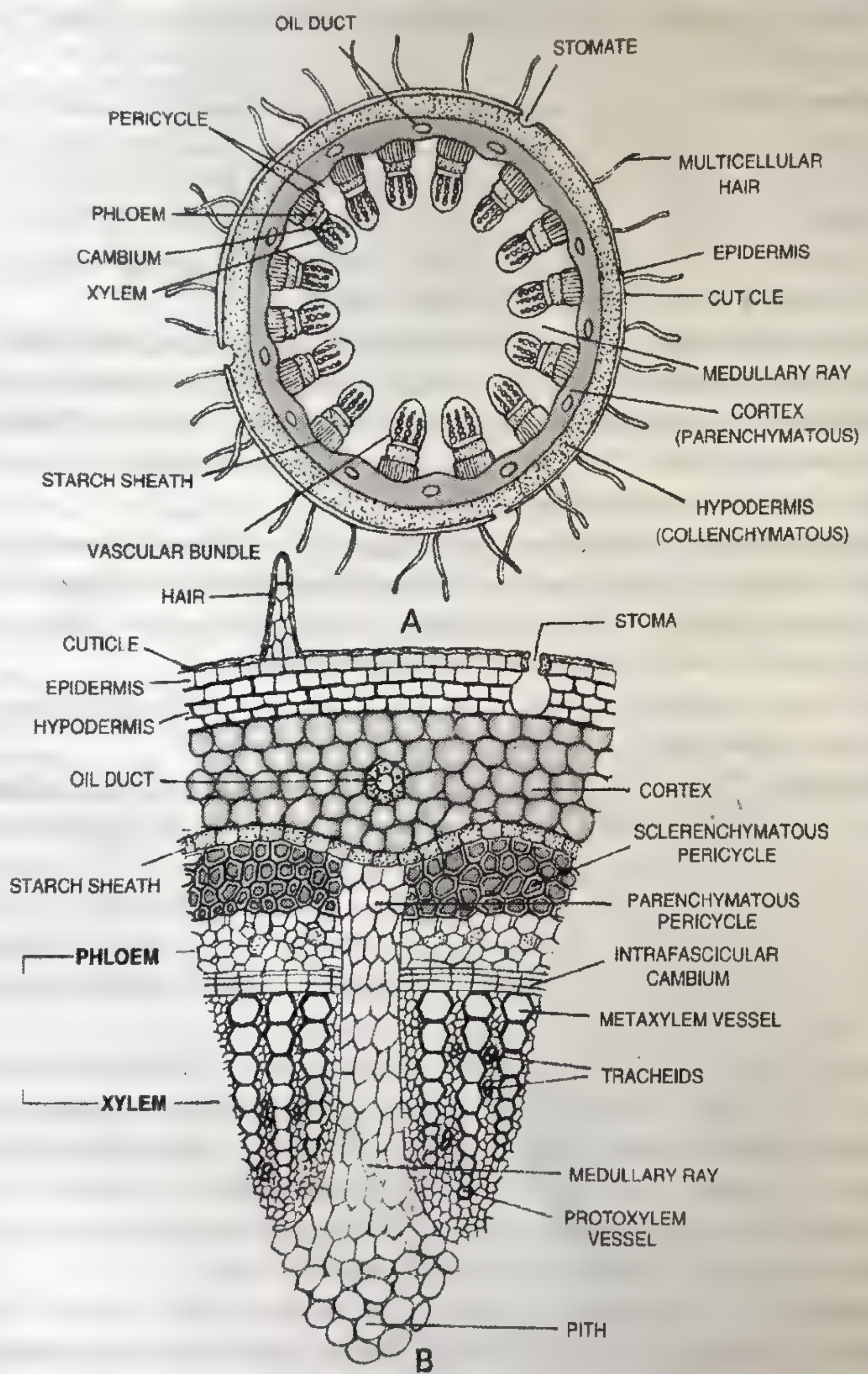


Fig. 6.27. A, T.S. Primary dicot stem of Sunflower (Diagrammatic); B, detailed structure of a part of T.S. stem of Sunflower.

bundles present around the central **pith** and inner to the **pericycle**. The vascular bundles are definite in number. They are obtusely wedge shaped. Each vascular bundle consists of **phloem** (primary) on the **outside, xylem** towards the **inner side** and strip of **cambium** in between the two. Phloem and xylem tissues lie on the **same radius**. Such vascular bundles are known as **conjoint** (with both phloem and xylem), **collateral** (phloem and xylem on the same radius) and **open** (with a strip of cambium in between phloem and xylem). Bicollateral open vascular bundles occur in the stem of *Cucurbita* and its relatives.

(a) **Phloem**. It lies towards the pericycle on the **outer** side of vascular bundle. Phloem consists of sieve tubes, companion cells, phloem parenchyma and some phloem fibres. The **companion cells** and **phloem parenchyma** are connected with sieve tubes through pits. They help in the **lateral flow** of the **organic food**. The **companion cells** also control the functions of the sieve tubes. The **sieve tubes** conduct organic food longitudinally.

(b) **Xylem**. It is **found towards** the **pith** or the **inner** portion of the vascular bundles. Xylem consists of two parts, smaller **protoxylem** (of narrow elements) and larger **metaxylem** (of broader elements). Protoxylem or first formed xylem lies at the tip of metaxylem towards the pith or centre of stem. Therefore, xylem is **endarch** (development centrifugal).

Xylem consists of **tracheids, vessels, xylem parenchyma** and **xylem fibres**. Out of these only the **xylem parenchyma** cells are living. They are smaller in size than the parenchyma cells found outside the bundles. Xylem parenchyma cells store food and help in the lateral conduction of the sap.

Vessels are present in the form of a few radial rows. They are angular in outline. The vessels of the **protoxylem** region are **smaller** and possess **annular** or **spiral** thickenings. These thickenings make the protoxylem vessels elastic and capable of stretching during the elongation of stem. The vessels of **metaxylem** have **pitted** thickenings.

Tracheids are present in between and around the radial rows of vessels especially of the metaxylem region. **Xylem fibres** lie scattered amongst the tracheids. The vessels, tracheids and xylem fibres, all provide **mechanical strength** to the stem. However, the most important function of xylem is the **conduction of water** and **mineral substances**. This is carried out by two tracheary elements, vessels and tracheids.

(c) **Cambium**. It is the leftout portion of procambium. Cambium is in the form of a **narrow strip** of primary **meristematic** cells that lie between the phloem and the xylem of a vascular bundle. It is called **intrafascicular** or **fascicular cambium**. Cambial cells are thin-walled fusiform cells which appear rectangular in transverse section.

Cambium helps in increasing the girth of stem by producing **secondary phloem** towards outside and **secondary xylem** towards the inner side (secondary growth).

7. **Medullary** or **Pith Rays**. They are the radial strips of parenchyma which are present **between** adjacent vascular bundles. The medullary rays **connect** the **pith** with **pericycle** and **cortex**. The ray cells are larger than cortical cells. They are polygonal in outline. Intercellular spaces are small. Ray cells make intimate contact with the conducting cells of both phloem and xylem through pits.

The medullary rays help in the **radial conduction** of food and water. They also transport gases from pith to cortex and *vice versa*.

8. **Pith** or **Medulla**. It forms the **centre** of the stem. The pith is made up of polygonal oval or rounded parenchyma cells which enclose intercellular spaces. The pith cells store food. In some dicots, the central part of the pith disintegrates to produce a cavity (pith cavity), *e.g.*, *Cucurbita*.

MONOCOT STEM (Fig. 6.28)

A monocot stem **lacks** secondary growth. It, therefore, possesses only the primary permanent tissues. The various tissues, unlike a dicot stem, are **not arranged** in concentric rings. The stem can be **solid** (*e.g.*, Maize, *Asparagus*) or **fistular** (with central cavity, *e.g.*, grass). A typical monocot stem (*e.g.*, Maize) consists of the following tissues (Fig. 6.28) :

1. **Epidermis**. It is the outermost layer of the stem which is made up of compactly arranged transparent, elongated and rectangular—barrel-shaped living parenchyma cells. The outer walls of epidermal cells possess deposition of silica and cutin. A separate layer of **cuticle** also occurs on the outside. The cuticle and cutinised epidermal cells prevent the evaporation of water from the stem. Silica provides stiffness. Hair are usually absent. At places the epidermis possesses **stomata** for gaseous exchange. Each stomate has two dumb-bell shaped guard cells.

2. **Hypodermis**. It is 2–3 layered thick and lies below the epidermis. Hypodermis is made up of thick walled lignified **sclerenchyma fibres**. It acts as heat screen and provides rigidity and mechanical strength to the stem.

3. **Ground Tissue**. It does not show distinction into cortex, endodermis, pericycle, pith and pith rays. The ground tissue is parenchymatous and occupies the whole stem interior. In the stem of Maize the cells are small and angular towards the hypodermis but become large and oval in the

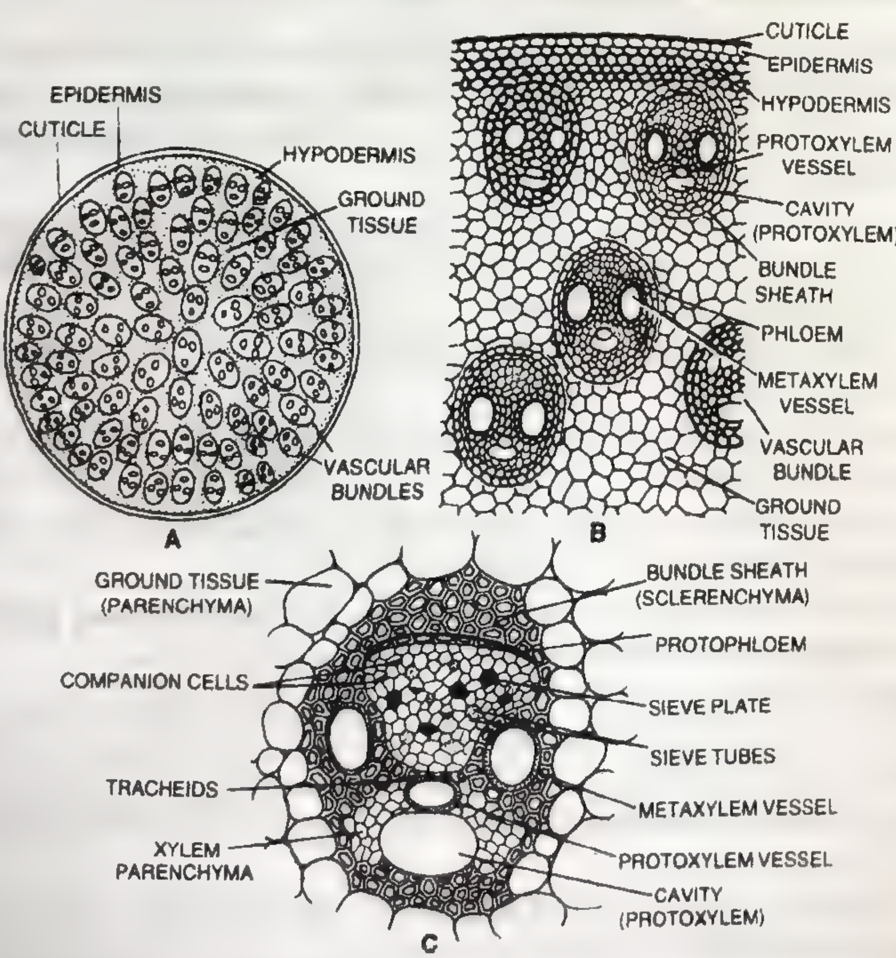


Fig. 6.28. T.S. Monocot stem of Maize (*Zea mays*). A, diagrammatic; B, part of T.S.; C, vascular bundle.

inner region. The ground tissue **stores food**. Some of the outer cells may also synthesize food due to the presence of chloroplasts in them (chlorenchymatous cells). Abundant intercellular spaces are present in the ground tissue. These spaces communicate with exterior through the stomata present in the epidermis.

4. **Vascular Strand.** The vascular strand is in the form of **atactostele** where a large **number of vascular bundles** lie scattered throughout the ground tissue. Vascular bundles are smaller but more numerous towards the outside than towards the centre.

The vascular bundles (Fig. 6.28 B,C) are oval or rounded in outline. They contain **both phloem** and **xylem**. Phloem lies towards the **outside** and the xylem on the **inner side**. **Cambium is absent** as the whole procambium is consumed in the formation of vascular tissues. The vascular bundles are, therefore, **conjoint, collateral** but **closed**. Each vascular bundle is surrounded by a sheath of sclerenchyma known as **bundle sheath**. The bundle sheath is more developed on the outer and the inner sides. Hypodermis and bundle sheaths coalesce in some of the outer vascular bundles. A bundle sheath is absent in *Asparagus*.

Phloem consists of sieve tubes, companion cells and a few phloem fibres. *Phloem parenchyma is absent.* The sieve tubes conduct organic food. In Maize, phloem is distinguished into outer **protophloem** and inner **metaphloem**. The protophloem gets crushed in the later stages.

Xylem is in the form of letter Y. It is **endarch**, *i.e.*, protoxylem lies towards the centre of the stem. Xylem is made up of vessels, tracheids, xylem parenchyma and a few xylem fibres. **Metaxylem** generally consists of two large oval or rounded vessels lying at the **upper** two angles of xylem. The metaxylem vessels have **pitted** walls. The two vessels are connected with each other by polygonal tracheids having pitted thickenings.

Protoxylem has a few (2–3) **small oval** vessels. They lie at **lower** angle of xylem. The vessels of protoxylem show **spiral** and **annular** thicknenings. Xylem parenchyma and a few fibres are found just outside them.

Some of the protoxylem vessels and xylem parenchyma cells dissolve or separate during the rapid growth of the stem to form a cavity called **protoxylem cavity** or **lacuna** (absent in *Asparagus*). The protoxylem cavity of Maize is **schizo-lysigenous** in origin. It generally stores water. The tracheids and vessels help in the conduction of sap as well as mechanical support. In Maize the protoxylem cavity and protophloem can be absent in the smaller vascular bundles.

Differences between Dicot and Monocot Stems

Dicot Stem	*Monocot Stem*
1. Stomata have kidney-shaped guard cells.	1. Stomata usually possess dumb bell-shaped guard cells.
2. The hypodermis is made up of collenchyma which may be green.	2. The hypodermis is formed of non-green sclerenchyma fibres.
3. The internal tissues are arranged in concentric layers.	3. The concentric arrangement of tissues is absent.
4. The ground tissue is differentiated into cortex, endodermis, pericycle, pith, etc.	4. The ground tissue is a mass of similar cells.
5. The stem is almost always solid.	5. The stem is generally hollow in the center (exception Maize).
6. The vascular bundles are arranged in ring around the pith.	6. The vascular bundles are scattered throughout the ground tissue.
7. Medullary rays occur in between vascular bundles for radial conduction.	7. Medullary rays are absent.

8. The vascular bundles are fewer in number and are of similar size.	8. The vascular bundles are numerous and are of different sizes— smaller towards the outside and larger towards the centre.
9. The vascular bundles are wedge-shaped in outline.	9. They are oval or rounded in outline.
10. No bundle sheath is present on the outside of a vascular bundle.	10. A sclerenchymatous bundle sheath is generally present on the outside of each vascular bundle.
11. The vascular bundles are open due to the presence of cambium in between phloem and xylem.	11. The vascular bundles are closed.
12. Phloem parenchyma is present in the phloem alongwith other elements.	12. Phloem parenchyma is absent.
13. The stem shows secondary growth due to the formation of secondary vascular tissues and periderm.	13. Secondary growth is usually absent.
14. Vessels are polygonal in outline.	14. Vessels are oval or rounded.
15. Vessels are usually arranged in chains or rows.	15. Vessels are arranged in a Y-shaped manner.
16. Metaxylem vessels are generally numerous.	16. Metaxylem vessels are a few in number.
17. A cavity is not found in the vascular tissues.	17. A cavity containing water is found in vascular bundle by the dissolution or separation of some protoxylem vessels and parenchyma cells lying nearby.
18. The older vascular tissues stop functioning after some time. They are replaced by younger vascular tissues.	18. The first formed vascular tissues continue functioning throughout the life of the plant.
19. The stem shows increase in diameter with age.	19. There is little increase in diameter with age.
20. Old stem is covered by a corky bark.	20. No additional structure is produced for protection of old stem. Persistent leaf bases occur in some.

Differences between Stem and Root

Stem	*Root*
A. MORPHOLOGY	
1. Stem arises from the plumule of embryo.	1. Root arises from the radicle of the embryo. It may also arise from any other part of the plant.
2. Stems are generally green, at least in the young state.	2. Roots are non-green.
3. It generally forms the ascending or above ground part of the plant (several exceptions).	3. The root is generally the descending or underground part of the plant (several exceptions).
4. Stem is differentiated into nodes and internodes.	4. Nodes and internodes are absent.
5. Stem bears leaves and buds on its nodes.	5. Both leaves and buds are absent.
6. A root cap or any other equivalent structure is absent.	6. A root cap is formed at the tip of the root.
7. Stem is generally positively phototropic, negatively hydrotropic and negatively geotropic.	7. Root is positively geotropic and hydrotropic, neutral or negatively phototropic.

8. The growing point of the stem is protected by young leaves.	8. The growing point of the root is protected by root cap.
9. The tip of stem possesses terminal bud.	9. A terminal bud is absent.
10. Growing point is terminal.	10. Growing point is subterminal.
11. Stem generally possesses multicellular hairs.	11. Root hairs are always unicellular.
12. Stem hairs are found all over the stem.	12. Root hairs are restricted to a particular area called root hair zone.
13. Stem hairs prevent the evaporation of water from the surface.	13. Root hairs help in the absorption of water from the soil.
14. The branches are exogenous or superficial in origin.	14. The root branches are endogenous or deep seated.
15. Stem branches develop from nodes.	15. Root branches do not arise from specific areas.
16. Stem branches are formed from axillary buds.	16. Root branches do not arise from buds.

B. ANATOMY

1. Cells of the epidermis have cutinised outer walls. A separate non-cellular layer of cuticle may also be formed on the outside.	1. Functional epiblema is without any cuticle or cutinised outer walls.
2. Epidermis is protective in function.	2. Young epiblema is absorptive in function.
3. Stomata are found on the stem.	3. Stomata are always absent.
4. Stem hairs usually do not arise as outgrowths of epidermal cells.	4. Root hairs are tubular outgrowths of the epidermal cells.
5. A collenchymatous or sclerenchymatous hypodermis is found below the epidermis.	5. Hypodermis is usually absent in young roots. A thick-walled exodermis is present in some cases.
6. A few outer cells of the ground tissues may contain chloroplasts.	6. Chloroplasts are almost invariably absent.
7. Cortex is narrow.	7. Cortex is broad.
8. Endodermis is not conspicuous.	8. Endodermis is conspicuous.
9. Pericycle, when present, is usually multi-layered.	9. Pericycle is commonly 1-2 layered.
10. Pericycle does not take part in secondary growth.	10. Pericycle is active in the formation of root branches and development of secondary growth.
11. Vascular bundles are conjoint and collateral.	11. Vascular bundles are radial, *i.e.*, phloem and xylem bundles are separate and are found on different radii.
12. Secondary vascular growth, when present, is by cambium which is both intrafascicular and interfascicular.	12. Secondary vascular growth when present arises from conjunctive parenchyma and pericycle.
13. Xylem is endarch.	13. Xylem is exarch.
14. Xylem and phloem contain fibres.	14. Fibres are generally absent.
15. The chief functions of the stem are storage, conduction and photosynthesis.	15. The chief functions of the root are absorption of water and mineral salts and anchorage.

SECONDARY GROWTH IN DICOT STEM

Primary growth produces growth in length and development of lateral appendages. Secondary growth is the formation of secondary tissues from lateral meristems. It increases the diameter of the stem. In woody plants, secondary tissues constitute the bulk of the plant. They take part in providing protection, support and conduction of water and nutrients. Secondary tissues are

formed by two types of lateral meristems, **vascular cambium** and **cork cambium** or **phellogen**. **Vascular cambium** produces **secondary vascular tissues** while phellogen forms **periderm**. Secondary growth occurs in perennial gymnosperms and dicots such as **trees** and **shrubs**. It is also found in the **woody stems** of some **herbs**. In such cases, the secondary growth is equivalent to one annual ring, *e.g.*, Sunflower.

A. Formation of Secondary Vascular Tissues. They are formed by the **vascular cambium**. Vascular cambium is produced by two types of meristems, **fascicular** or **intrafascicular** and **interfascicular** cambium. Intrafascicular cambium is a primary meristem which occurs as strips in vascular bundles. Interfascicular cambium arises secondarily from the cells of medullary rays which occur at the level of intrafascicular strips. These two types of meristematic tissues get connected to form a ring of **vascular cambium**. Vascular cambium is truely single layered but appears to be a few layers (2–5) in thickness due to presence of its immediate derivatives. Cells of vascular cambium divide periclinally both on the outer and inner sides (bipolar divisions) to form secondary permanent tissues.

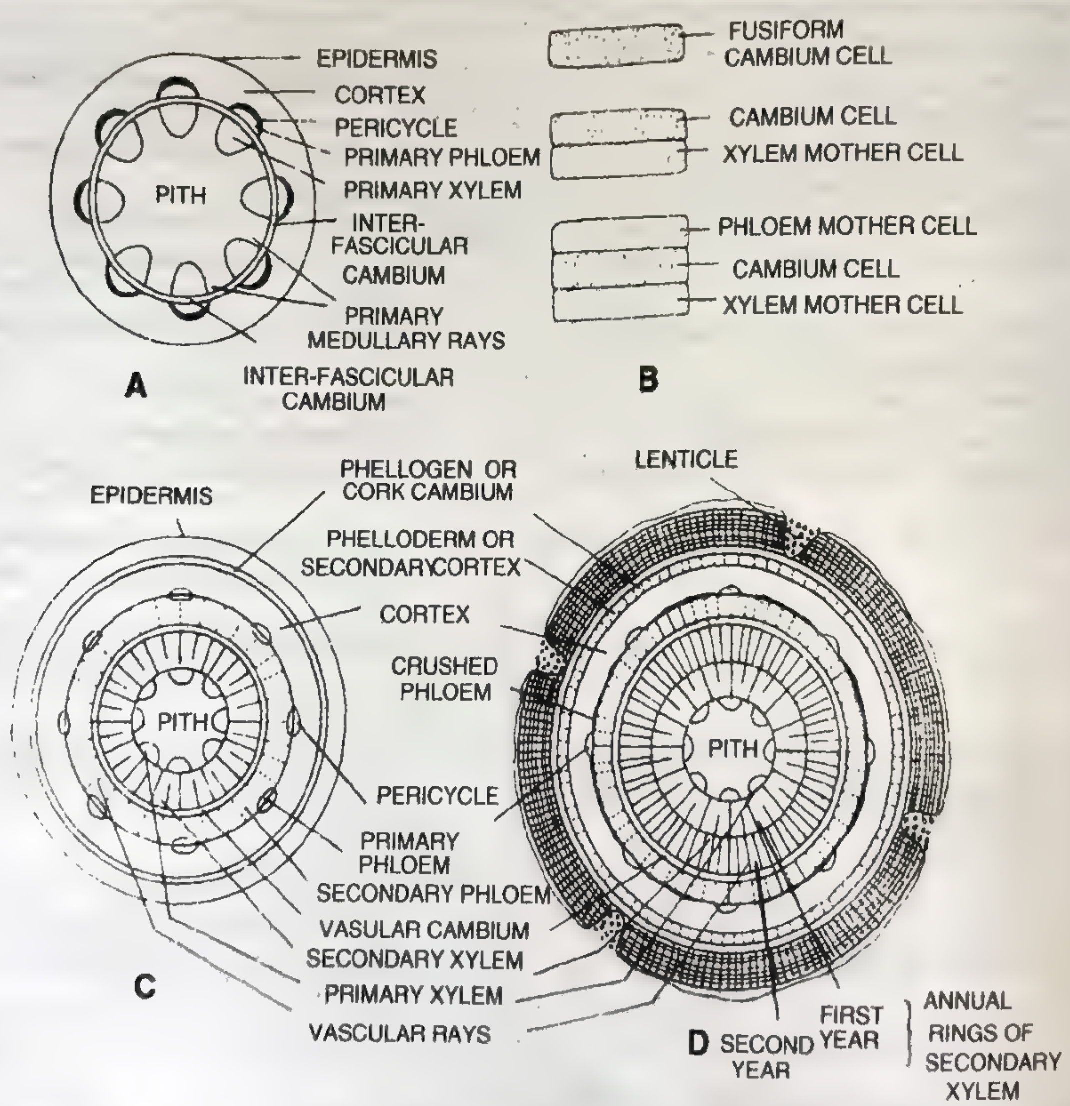


Fig. 6.29. A, complete ring of vascular cambium formed by strips of intrafascicular cambium and inter-fascicular cambium. B, formation of secondary vascular tissue mother cells; C, the beginning of secondary growth (mostly made up of secondary vascular tissues) of dicot stem (diagrammatic); D, two-year stage of secondary growth of a dicot stem.

The cells of vascular cambium are of two types, elongated spindle-shaped **fusiform initials** and shorter isodiametric **ray initials** (Fig. 6.30). Both appear rectangular in T.S. Ray initials give rise to **vascular rays.** Fusiform initials divide to form **secondary phloem** on the outer side and **secondary xylem** on the inner side (Fig. 6.29 B). With the formation of secondary xylem on the inner side, the vascular cambium moves gradually to the outside by adding new cells. The phenomenon is called **dilation**. New ray cells are also added. They form additional rays every year (Fig. 6.29 D). The vascular cambium undergoes two types of divisions— **additive** (periclinal divisions for formation of secondary tissues) and **multiplicative** (anticlinal divisions for dilation). Ray initials produce **radial system** (= horizontal or transverse system) while fusiform initials form axial system (= vertical system) of secondary vascular tissues.

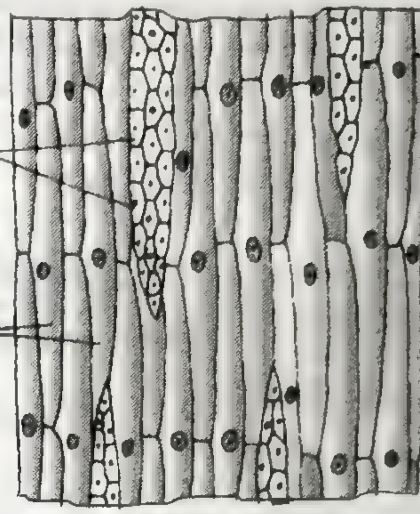


Fig. 6.30. L.S. Vascular cambium showing fusiform and ray initials.

Differences between Fascicular Cambium and Interfascicular Cambium

Fascicular (Intrafascicular) Cambium	*Interfascicular Cambium*
1. It is a primary meristem.	1. It is a secondary meristem.
2. Fascicular cambium is present even in the primary stem.	2. Interfascicular cambium develops only when secondary growth is to occur.
3. Fascicular or intrafascicular cambium lies inside vascular bundles of the stem.	3. Interfascicular cambium is formed in between the vascular bundles.
4. It is derived from procambium of stem apical meristem.	4. It develops from permanent cells of medullary rays through the process of dedifferentiation.

1. **Vascular Rays**. The vascular rays or **secondary medullary rays** are rows of radially arranged cells which are formed in the secondary vascular tissues. They are a few cells in height. Depending upon their breadth, the vascular rays are **uniseriate** (one cell in breadth) or **multiseriate** (two or more cells in breadth). Vascular rays may be **homocellular** (having one type of cells) or **heterocellular** (with more than one type of cells). The cells of the vascular rays enclose intercellular spaces. The part of the vascular ray present in the secondary xylem is called **wood** or **xylem** ray while the part present in the secondary phloem is known as **phloem ray**.

The vascular rays conduct water and organic food and permit diffusion of gases in the radial direction. Besides, their cells store food.

2. **Secondary Phloem (Bast)**. It forms a narrow circle on the outer side of vascular cambium. Secondary phloem does not grow in thickness because the primary and the older secondary phloem present on the outer side gets crushed with the development of new functional phloem (Fig. 6.29 D). Therefore, rings (annual rings) are not produced in secondary phloem. The crushed or non-functioning phloem may, however, have fibres and sclereids.

Secondary phloem is made up of the same type of cells as are found in the primary phloem (metaphloem)— sieve tubes, companion cells, phloem fibres and phloem parenchyma. Phloem parenchyma is of two types— **axial** phloem parenchyma made up of longitudinally arranged cells and phloem **ray** parenchyma formed of radially arranged parenchyma cells that constitute

the part of the vascular ray present in the phloem (Fig. 6.32). Elements of secondary phloem show a more regular arrangement. Sieve tubes are comparatively more numerous but are shorter and broader. Sclerenchyma fibres occur either in patches or bands. Sclereids are found in many cases. In such cases secondary phloem is differentiated into **soft bast** (secondary phloem without fibres) and **hard bast** (part of phloem with abundant fibres).

Differences between Primary Phloem and Secondary Phloem

Primary Phloem	*Secondary Phloem*
1. It is formed from procambium of apical meristem.	1. Secondary phloem develops from a lateral meristem called vascular cambium.
2. It is found in the primary plant body of all vascular plants.	2. It is found only during secondary growth of dicots and gymnosperms with the exception of annuals.
3. Primary phloem occurs in all types of organs.	3. Secondary phloem is restricted to stems and roots of perennial dicots and gymnosperms.
4. It occurs towards the periphery.	4. It is formed inner to the primary phloem.
5. Primary phloem is differentiated into protophloem and metaphloem.	5. There is no such distinction.
6. A radial system is absent.	6. It is traversed by radial system of phloem rays.
7. Phloem fibres are fewer. They are restricted to outer part.	7. Phloem fibres are more abundant. They commonly occur in patches or bands.
8. Primary phloem shows an irregular arrangement of various types of cells.	8. Secondary phloem has a more regular arrangement.
9. Sieve tubes are comparatively fewer.	9. Sieve tubes are comparatively more numerous.
10. Sieve tubes are longer and narrower.	10. Sieve tubes are shorter but wider.
11. Phloem parenchyma is less abundant.	11. It is more abundant.
12. Crystals and other depositions are rare.	12. The cells often contain crystals and depositions of various substances.
13. Sclereids are usually absent.	13. Sclereids are formed in the secondary phloem of several plants.

3. **Secondary Xylem**. It forms the bulk of the stem and is commonly called wood. The secondary xylem consists of vessels, tracheids (both tracheary elements), wood fibres and wood parenchyma. Wood parenchyma may contain tannins and crystals besides storing food. It is of two types— **axial** parenchyma cells arranged longitudinally and **radial** ray parenchyma cells arranged in radial or horizontal fashion. The latter is part of vascular ray present in secondary xylem. Secondary xylem does not show distinction into protoxylem and metaxylem elements. Therefore, vessels and tracheids with annular and spiral thickenings are absent. The tracheary elements of secondary xylem are similar to those of metaxylem of the primary xylem with minor differences. They are comparatively shorter and more thick-walled. Pitted thickenings are more common. Fibres are abundant.

Width of secondary xylem grows with the age of the plant. The primary xylem persists as conical projection on its inner side. Pith may become narrow and ultimately get crushed. The yearly growth of secondary xylem is distinct in the areas which experience **two seasons**, one **favourable** (spring or rainy season) and the other **unfavourable** (autumn, winter or dry summer). In favourable season the temperature is optimum. There is a good sunshine and humidity. At this time the newaly formed leaves produce hormones which stimulate cambial activity. The activity decreases and stops towards the approach of unfavourable season. Hence the annual or yearly

growth appears in the form of distinct rings which are called **annual rings** (Fig. 6.31). Annual rings are formed due to sequence of rapid growth (favourable season, *e.g.*, spring), slow growth (before the onset of unfavourable period, *e.g.*, autumn) and no growth (unfavourable season, *e.g.*, winter). Annual rings are not distinct in tropical areas which do not have long dry periods.

Annual Rings (Growth Rings). It is the wood formed in a single year. It consists of two types of wood, **spring wood** and **autumn wood** (Fig. 6.32). The **spring** or **early wood** is **much wider** than the **autumn** or **late wood**. It is Lighter in colour and of lower density. Spring wood consists of **larger** and **wider** xylem elements. The **autumn** or late wood is dark coloured and of higher density. It contains compactly arranged **smaller** and **narrower** elements which have comparatively thicker walls. In autumn wood, tracheids and fibres are more abundant than those found in the spring wood.

Fig. 6.31. Part of T.S. old stem showing annual rings.

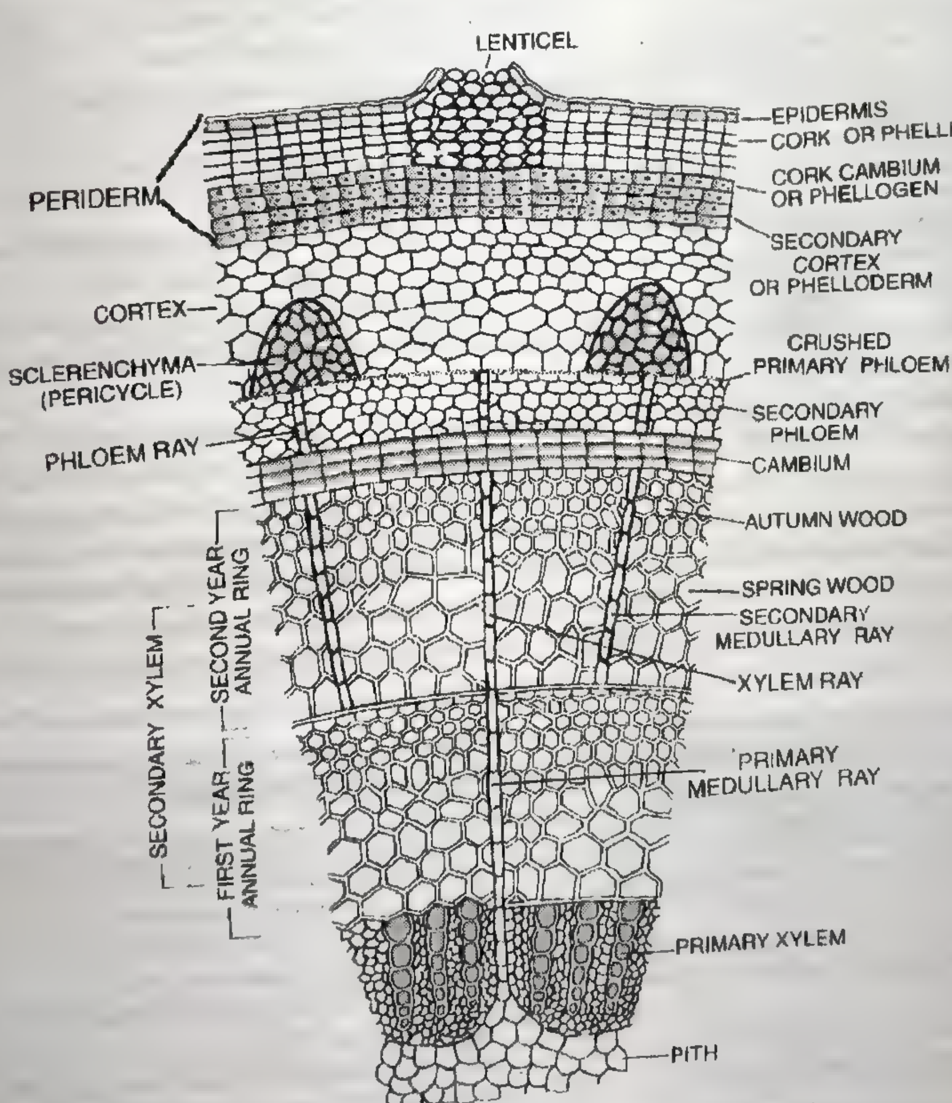


Fig. 6.32. Part of detailed structure of transverse section of two year old dicot stem showing secondary growth.

The **transition** from spring to autumn wood in an annual ring is **gradual** but the transition from autumn wood to the spring wood of the next year is **sudden**. Therefore, each year's growth is quite distinct. The number of annual rings corresponds to the age of that part of the stem. (They can be counted by **increment borer**). Besides giving the age of the plant, the annual rings also give some clue about the climatic conditions of the past through which the plant has passed. **Dendrochronology** is the science of counting and analysing annual growth rings of trees.

Differences between Spring Wood and Autumn Wood	
Spring Wood (Early Wood)	*Autumn Wood* (Late Wood)
1. It is produced during the favourable period of the year.	1. It is formed towards the close of the active growing period of the year just before the arrival of unfavourable period.
2. Spring wood constitutes the major part of the annual ring.	2. Autumn wood forms a narrow strip in the annual ring.
3. It occurs in the beginning of an annual ring.	3. Autumn wood occurs at the end of an annual ring.
4. It contains larger and wider elements.	4. Autumn wood is formed of smaller and narrower elements.
5. Fibres are fewer.	5. Fibres are abundant.
6. The wood is lighter in colour.	6. The wood is darker.
7. The tracheary elements are comparatively less thickened.	7. The tracheary elements are comparatively more thickened.
8. It has lower density.	8. It has higher density.

Softwood and Hardwood. Softwood is the technical name of gymnosperm wood because it is devoid of vessels. Several of the softwoods are very easy to work with (*e.g., Cedrus, Pinus* species). However, all of them are not 'soft'. The softness depends upon the content of fibres and vascular rays. 90–95% of wood is made of tracheids and fibres. Vascular rays constitute 5–10% of the wood.

Hardwood is the name of dicot wood which possesses abundant vessels. Due to the presence of vessels, the hardwoods are also called **porous woods**. In *Cassia fistula* and *Dalbergia sisso* the vessels are comparatively very broad in the spring wood while they are quite narrow in the autumn wood. Such a secondary xylem or wood is called **ring porous**. In others (*e.g., Syzygium cumini*) larger sized vessels are distributed throughout spring wood and autumn wood. This type of secondary xylem or wood is known as **diffuse porous**. Ring porous wood is more advanced than diffuse porous wood as it provides for better translocation when the requirement of the plant is high.

Differences between Softwood and Hardwood	
Softwood	*Hardwood*
1. It is the name of gymnosperm wood.	1. Hardwood is the name of dicot wood.
2. The wood is devoid of vessels. It is, therefore, also called **nonporous wood**.	2. The wood contains vessels. It is, therefore, called **porous wood**.
3. The content of tracheids can be 90-95%.	3. The content of the tracheids is very low (less than 5%).
4. Wood or xylem fibres are fewer.	4. Wood or xylem fibres are abundant.
5. The wood is easy to work with.	5. The wood is comparatively difficult to work with.

Sapwood and Heartwood. The wood of the older stems (*Dalbergia, Acacia*) gets differenti-

ated into two zones, the outer **light** coloured and functional **sapwood** or **alburnum** and the inner darker and nonfunctional **heartwood** or **duramen** (Fig. 6.34). The tracheids and vessels of the heart wood get plugged by the ingrowth of the adjacent parenchyma cells into their cavities through the pits. These ingrowths are called **tyloses** (Fig. 6.33). Ultimately, the parenchyma cells become lignified and dead. Various types of plant products like **oils, resins, gums, aromatic substances, essential oils** and **tannins** are deposited in the cells of the heartwood. These substances are collectively called **extractives**. They provide **colour** to the heartwood. They are also **antiseptic**. The heartwood is, therefore, stronger and more durable than the sapwood. It is resistant to attack of insects and microbes. Heart wood is commercial source of Cutch (*Acacia catechu*), Haematoxylin (*Haematoxylon campechianum*), Brasilin (*Caesalpinia sappan*) and Santalin (*Pterocarpus santalinus*). Heartwood is, however, liable to be attacked by wood rotting fungi. Hollow tree trunks are due to their activity.

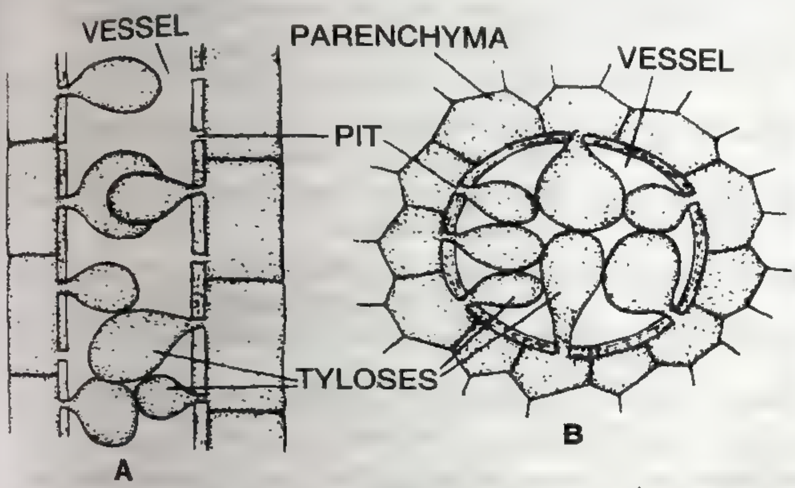


Fig. 6.33. Formation of tyloses in heartwood. A, L.S. vessel showing tyloses.

Fig. 6.34. Sapwood and heartwood

Differences between Sapwood or Alburnum and Heartwood or Duramen

Sapwood (Alburnum)	*Heartwood* (Duramen)
1. It is outer wood of an old stem.	1. It is the central wood of an old stem.
2. It is light coloured.	2. Heartwood is dark coloured.
3. Living cells are present.	3. Living cells are absent.
4. Sapwood is the functional part of the secondary xylem or wood.	4. Heartwood is the nonfunctional part of secondary xylem.
5. The tracheary elements are not plugged by tyloses.	5. The tracheary elements are plugged by tyloses.
6. Tracheary elements do not possess any deposition in their lumen.	6. Tracheary elements have deposition of tannins, resins, gums, etc.
7. Sapwood or alburnum is lighter.	7. Heartwood is heavier.
8. It is less durable because it is susceptible to attack by pathogens and insects.	8. It is more durable due to its little susceptibility to the attack of pathogens and insects.

Differences between Primary and Secondary Xylem	
Primary xylem	*Secondary xylem*
1. It is formed from procambium of apical meristem.	1. Secondary xylem is produced from lateral meristem, called vascular cambium.
2. It occurs in the primary plant body of all vascular plants.	2. Secondary xylem is formed during secondary growth only.
3. Primary xylem is found in all types of organs.	3. It is restricted to stems and roots of only perennial dicots and gymnosperms.
4. It occurs towards the center.	4. It occurs towards the outer side of primary xylem.
5. Primary xylem occurs in patches.	5. Secondary xylem forms a cylinder.
6. The xylem is differentiated into two parts. protoxylem and metaxylem.	6. There is no such distinction.
7. A radial system is absent.	7. It is traversed by a radial system of xylem rays.
8. Annual rings are absent.	8. It may show annual rings.
9. There is no distinction into sapwood and heartwood.	9. A distinction into sapwood and heartwood is found in large woody plants.
10. Fibres are few or absent.	10. Fibres are generally abundant.
11. The tracheids and vessels are long and comparatively less thick-walled.	11. The tracheids and vessels are comparatively shorter and more thick-walled.
12. All types of thickenings can occur in tracheary elements.	12. Usually pitted thickenings occur in the tracheary elements.
13. Tyloses are usually absent.	13. The vessels and tracheids of older xylem get blocked by the development of tyloses.

B. Formation of Periderm. In order to provide for increase in girth and prevent harm on the rupturing of the outer ground tissues due to the formation of secondary vascular tissues, dicot stems produce a **cork cambium** or **phellogen** in the outer cortical cells. Rarely it may arise from the epidermis (*e.g.*, Teak, Oleander), hypodermis (*e.g.*, Pear) or phloem parenchyma.

Phellogen cells divide on both the outer side as well as the inner side (bipolar) to form secondary tissues. The **secondary tissue** produced on the **inner side** of the phellogen is parenchymatous or collenchymatous. It is called **secondary cortex** or **phelloderm**. Its cells show radial arrangement.

Phellogen produces **cork** or **phellem** on the outer side. It consists of dead and compactly arranged rectangular cells that possess suberised cell walls. The cork cells contain tannins. Hence, they appear brown or dark brown in colour. The cork cells of some plants are filled with air *e.g., Quercus suber* (Cork Oak or Bottle Cork). The phelloderm, phellogen and phellem together constitute the **periderm** (Fig. 6.35).

Cork prevents the loss of water by evaporation. It also protects the interior against entry of harmful micro-organisms, mechanical injury and extremes of temperature. Cork is light, compressible, nonreactive and sufficiently resistant to fire. It is used as stopper for bottles, shock absorption and insulation. At places phellogen produces aerating pores instead of cork. These pores are called **lenticels**. Each lenticel is filled by a mass of somewhat loosely arranged suberised cells called **complementary cells**.

Lenticels. Lenticels are aerating pores in the bark of plants. They appear on the surface of the bark as raised scars containing oval, rounded or oblong depressions (Fig. 6.35 A). They occur in woody trees but not in climbers. Normally they are formed in areas with underlying rays for facilitating gas exchange. Lenticels may occur scattered or form longitudinal rows.

A lenticel is commonly produced beneath a former stomate or stoma of the epidermis. Its margin is raised and is formed by surrounding cork cells. The lenticel is filled up by loosely arranged thin walled rounded and suberised (*e.g., Prunus*) or unsuberised cells called **complementary cells** (Fig. 6.35. B). They enclose intercellular spaces for gaseous exchange. The complementary cells are formed from loosely arranged phellogen cells and division of substomatal parenchyma cells. The suberised nature of complementary cells checks excessive evaporation of water.

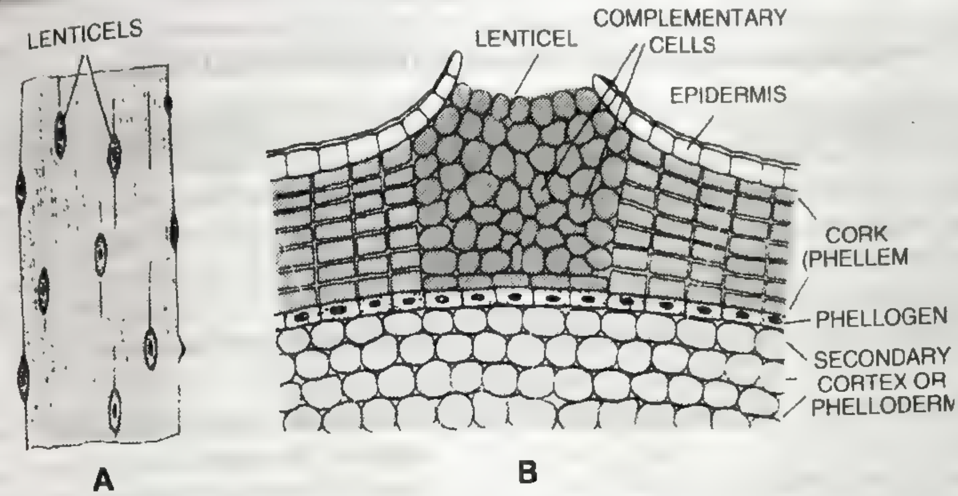


Fig. 6.35. Lenticels. A, external view of lenticels; B, T.S. lenticel.

In temperate plants the lenticels get closed during the winter by the formation of compactly arranged **closing cells** over the complementary cells.

Bark. In common language and economic botany, all the dead cells lying outside phellogen are collectively called bark*. The outer layers of the bark are being constantly peeled off on account of the formation of new secondary vascular tissues in the interior. The peeling of the bark may occur in sheets (sheets or ring bark, *e.g., Eucalyptus*) or in irregular strips (scaly bark). The scaly bark is formed when the phellogen arises in strips instead of rings, *e.g., Acacia* (*vern.* Kikar). Bark formed in early growing season is **early** or **soft bark.** The one formed towards end of growing season is **late** or **hard bark.**

Bark is insect repellent, decay proof, fire-proof and acts as a heat screen. Commercially it is employed in tanning (*e.g., Acacia*), drugs (*e.g., Cinchona*— quinine) or as spice (*e.g.,* Cannamon, *vern.* Dalchini). The cork of *Quercus suber* is employed in the manufacture of bottle stoppers, insulators, floats, sound proofing and linoleum.

Differences between Phellem and Phelloderm

Phellem	*Phelloderm*
1. Phellem or cork is a tissue formed on the outer side of phellogen or cork cambium.	1. Phelloderm or secondary cortex is produced on the inner side of phellogen.
2. It is composed of dead cells.	2. Phelloderm is made of living cells.
3. Phellem is protective in function.	3. Its cells take part in storage of food.
4. The cell walls become impermeable due to suberisation.	4. Suberisation is absent.

* In anatomical and physiological usages bark includes all tissues outside the vascular cambium. It is then differentiated into outer bark or rhytidome (consisting of dead cells) and inner bark (of living cells, *i.e.*, periderm and secondary phloem).

5. Phellem cells are filled with tannins.	5. Tannins are absent.
6. The cells are compactly arranged except for the presence of lenticels.	6. The cells enclose small intercellular spaces.
7. Phellogen is more active on the side of phellem, *i.e.*, more phellem is formed as compared to phelloderm.	7. Phellogen is less active on the side of phelloderm, *i.e.*, less phelloderm is formed as compared to phellem.
8. The outer part of the phellem is peeled off at intervals.	8. There is no loss of phelloderm.

Differences in Secondary Growth of Dicot Stems and Roots

Dicot Stem	*Dicot Root*
1. The vascular cambium is in the form of a circular strip or ring from the beginning.	1. The vascular cambium is a wavy band in the early stages of its activity.
2. The vascular cambium is made up of both primary (intra-fascicular) and secondary (interfascicular) strips of meristematic tissues.	2. The vascular cambium is secondary in origin. It is formed of conjunctive parenchyma and pericycle.
3. The vascular rays are narrow from the beginning.	3. Initially the vascular rays are wide and arise opposite the protoxylem points.
4. Ray initials are not grouped in a particular region.	4. Ray initials arise from the pericycle part of vascular cambium.
5. Annual rings are quite common.	5. Annual rings are absent.
6. Phellogen arises from a superficial layer of the cortex.	6. Phellogen generally originates from the pericycle.

Significance of Secondary Growth

1. Secondary growth adds to the girth of the plant. It provides support to increasing weight of the aerial growth.

2. Secondary growth produces a corky bark around the tree trunk that protects the interior from abrasion, heat, cold and infection.

3. It adds new conducting tissues for replacing old nonfunctioning ones as well as for meeting increased demand for long distance transport of sap and organic nutrients.

Anomalous Secondary Growth

It is abnormal type of secondary growth that occurs in some arborescent monocots (*e.g.*, *Dracaena, Yucca, Agave*) and storage roots (*e.g.*, Beet, Sweet Potato). In arborescent monocot stems, a secondary cambium grows in hypodermal region. The latter forms conjunctive tissue and patches of meristematic cells. The meristematic patches grow into secondary vascular bundles. Anomalous vascular bundles also occur in cortex (cortical bundles, *e.g.*, *Nyctanthes*) and pith (*e.g.*, *Boerhaavia*). In storage roots (*e.g.*, Beet), accessory cambial rings appear on the outside of endodermis. They produce less secondary xylem but more secondary phloem. The secondary phloem contains abundant **storage parenchyma**.

LEAF

Types of Leaves

Anatomically there can be three types of leaves— dorsiventral (bifacial), isobilateral (equifacial) and unifacial.

1. **Dorsiventral** (Bifacial). The leaves are commonly horizontal in orientation with distinct

upper and lower surfaces. The upper surface is also called **inner, adaxial** or **ventral surface**. The lower surface is correspondingly called **outer, abaxial** or **dorsal surface**. Mesophyll is distinguishable into palisade and spongy tissues with palisade usually restricted to the upper side. Most of the **dicotyledonous leaves are dorsiventral.**

2. **Isobilateral** (Equifacial). The leaf is placed in such a way that both its surfaces receive equal amount of sunlight. A distinction into upper and lower surfaces is absent. Mesophyll is usually indistinguishable (or palisade tissue is present in equal amount on both the sides). Most of the **monocotyledonous leaves are isobilateral.**

3. **Unifacial.** A distinction into upper and lower surfaces is absent. The leaves are generally cylindrical, *e.g.*, Onion.

Dorsiventral Mesophytic Leaf

The upper or adaxial surface which faces the sun is darker than the lower or abaxial surface. The different parts are (Fig. 6.36) :

1. **Upper or Adaxial Epidermis.** It consists of a single layer of tightly packed rectangular-barrel shaped transparent parenchymatous cells which are devoid of chloroplasts. The inner and the radial walls of the epidermal cells are thin. The outer walls are cutinised. A distinct layer of **cuticle** lies on the outside of the epidermis. The cuticle prevents excessive transpiration, helps bind epidermal cells and protects them from mechanical injury.

Hair may occur here and there. They are also covered over by a layer of cuticle. Mesophytic leaves may have stomata in the upper epidermis.

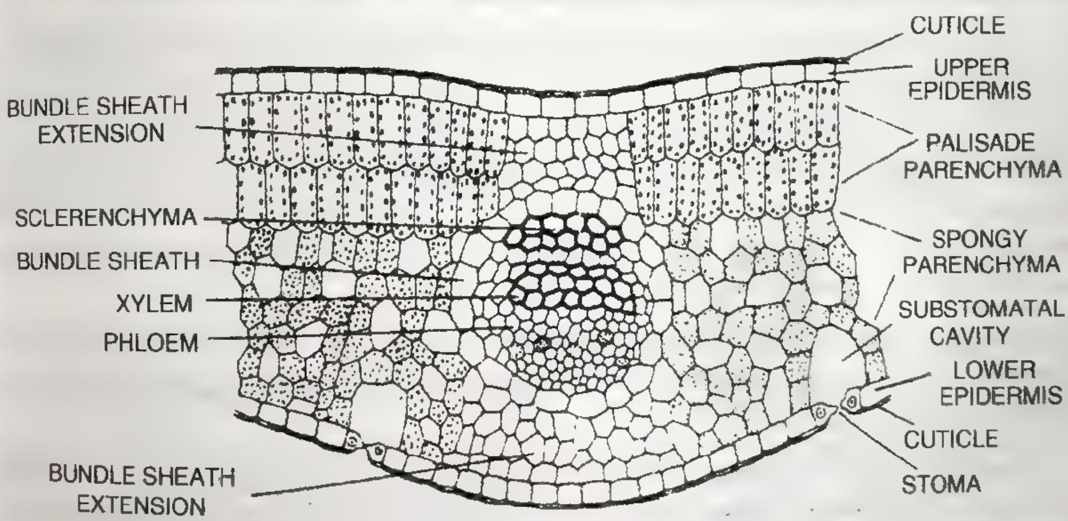


Fig. 6.36. V.S. dorsiventral leaf.

2. **Lower or Abaxial Epidermis.** It bounds the leaf on the lower surface. The abaxial epidermis consists of a single layer of compactly arranged rectangular transparent parenchymatous cells. Their outer or lower walls are cutinised. A distinct layer of **cuticle** is also present. The cuticle is, however, less developed than at the adaxial epidermis. Hair may occur here and there. They are usually multicellular and are covered by a layer of cuticle.

The abaxial epidermis contains a large number of pores called stomata or **stomates**. They lead internally into **substomatal cavities or chambers**. Substomatal cavities are connected with intercellular spaces of mesophyll. Each stoma or stomate has a narrow pore bounded and controlled

by two small specialised kidney-shaped epidermal cells called **guard cells**. Their stomatal walls are thicker than the rest. Unlike other epidermal cells, the guard cells possess a few chloroplasts. The **opened stomata allow** the gaseous exchange between the interior of the leaf and the atmosphere. Incidentally this also causes transpiration. In many plants the two guard cells are associated with two or more specialized epidermal cells called **accessory** or **subsidiary cells** . Depending upon the distribution of stomata on the leaf surface, leaf is called **hypostomatic** (stomata only on lower surface) and **amphistomatic** (stomata on both surfaces).

The various functions of the epidermis are (i) protection of internal tissues (ii) exchange of gases through stomates (iii) loss of water vapours or transpiration through stomata (iv) reducing the rate of surface transpiration by the presence of cuticle (v) reducing the rate of transpiration by forming a stationary layer of air with the help of hair (vi) protection from microbial attack due to presence of cuticle.

3. **Mesophyll** (Gk. *meson*— middle, *phyllon*— leaf). The interior of the leaf, between the upper and the lower epidermis, contains veins and a parenchymatous green tissue or **chlorenchyma**. The chlorenchyma of leaf is known as **mesophyll**. Mesophyll is usually differentiated into two regions, upper **palisade** and lower **spongy**.

The **palisade parenchyma** or **palisade mesophyll** lies below the upper epidermis. It consists of 1-3 layers of vertically elongated, parallel and closely placed columnar or cylindrical cells. The long axes of these parenchyma cells lie at right angles to the surface of the leaf. The palisade mesophyll cells enclose a number of narrow intercellular spaces for exchange of gases. The compactness of palisade tissue is directly dependent upon the light intensity to which the leaf is exposed. The palisade parenchyma or palisade mesophyll cells are rich in discoid chloroplasts. They are, therefore, the main seat of **photosynthesis**.

The **spongy parenchyma** or **spongy mesophyll** lies between the lower epidermis and the palisade parenchyma. Its cells may have various outlines like oval, rounded, irregular, lobed or branched. They have chloroplasts but fewer than present in the palisade parenchyma. The cell walls are thin but are suberised and unwettable in many species. The spongy cells are very loosely arranged except around the vascular bundles. They enclose large cavities or **intercellular spaces** which are connected with the atmosphere through the stomata. For this a large **substomatal cavity** lies below each stoma.

As the chloroplasts are more abundant in the compact palisade mesophyll cells than the loosely arranged spongy mesophyll cells, the upper surface of the leaf appears deeper green as compared to the lower surface.

4. **Vascular System** or **Strand**. It is made up of a number of vascular bundles of varying sizes depending upon the venation. The vascular bundles of ribs are thicker than those of lateral veins.

The vascular bundles are generally found at the boundary between the palisade and the spongy regions. Each vascular bundle is surrounded by a sheath of compactly arranged parenchyma cells called **bundle sheath**. The bundle sheath of the larger veins show parenchymatous **extensions** towards both the upper and lower sides.

The vascular bundles are almost rounded. They are **conjoint** and **collateral**, *i.e.*, they possess both phloem and xylem which lie on the same radius. **Xylem** lies towards the **upper** side of the leaf while **phloem** is found towards the **lower** surface. Xylem consists of vessels, tracheids, xylem parenchyma and a few xylem fibres. The **vessels** and **tracheids** conduct water and mineral salts besides providing mechanical support to the leaf. **Xylem parenchyma** stores food and allows lateral movement of water and mineral salts. **Xylem fibres**, when present, give additional strength to the leaf.

Phloem is made up of sieve tubes, companion cells and phloem parenchyma. Phloem fibres are rarely present. Sieve tubes conduct organic food. **Phloem parenchyma** cells store food and help in the lateral conduction of food. Companion cells are supposed to control the function of sieve tubes.

On the outer side of the vascular tissues of a bundle may be found a few layers of **sclerenchyma fibres**. They are, however, more abundant on the upper region just above the xylem. They provide rigidity and mechanical strength to the leaf.

5. **Midrib**. Mesophyll is absent in the region of midrib and other larger veins. Collenchyma or sclerenchyma occurs towards the two epidermal layers for providing mechanical strength. The centre contains a number of vascular bundles which are embedded in a parenchymatous ground tissue.

Isobilateral Leaf (Typical Monocot Leaf, Fig. 6.37)

The isobilateral monocot leaves usually do not show a distinction into petiole and lamina. The leaf base is commonly sheathing, that is, covering the stem partially or completely. The venation is parallel. Both the surfaces can face the sun. Therefore, the two surfaces are equally green (Gk. *iso*— equal, *bi*— two, *lateris*— side). The internal structure also does not show much differentiation of upper and lower sides. The various parts of a typical isobilateral leaf (*e.g.*, Maize) are as follows:

1. **Epidermis**. A uniseriate or single-layered epidermis occurs on the two sides of the leaf. The epidermis consists of compactly arranged oval rectangular transparent parenchymatous cells. The cells are thickened on the free side where silica and cutin are deposited. A distinct layer of cuticle occurs on the outside.

At places the upper or adaxial epidermis contains groups of larger thin-walled protruding and turgid cells over the region of veins. They are called **bulliform** or **motor cells**. The cells are highly vacuolate and can store water, if available. However, in case of water deficiency the bulliform cells lose water and become flaccid. As a result the leaf gets rolled up to reduce the exposed surface. The bulliform cells are also useful in the unrolling of leaf during its development.

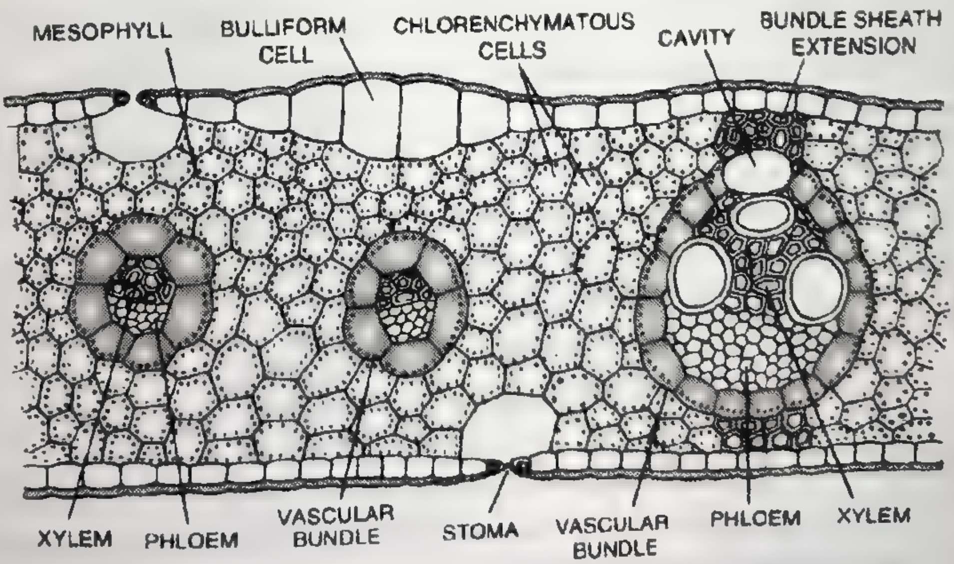


Fig. 6.37. V.S. or T.S. portion of Maize (or Monocot) Leaf.

Both the surfaces contain **stomata**. The leaf is, therefore, **amphistomatic**. Each stoma or stomate is lined by a pair of dumb bell-shaped **guard cells**. Unlike other epidermal cells, guard cells contain a few chloroplasts. The guard cells are further associated with a pair of specialized epidermal cells called **subsidiary cells** or **accessory cells**. Due to their peculiar thickening the guard cells can create a pore in between them when they get swollen due to endosmosis. Each stomate or stoma leads internally into an air space called **substomatal cavity** or **chamber.**

The various functions of the epidermis are (i) protection of internal tissues (ii) protection from microbial attack due to cuticle and silica (iii) gaseous exchange through stomata (iv) allowing transpiration through stomata (v) reduction in the rate of transpiration through epidermal cells due to the presence of cuticle (vi) folding of leaves during drought with the help of bulliform or motor cells (vii) unfolding of the young leaves by means of motor or bulliform cells.

2. **Mesophyll.** It lies in between the two layers of epidermis. Mesophyll is not differentiated into palisade and spongy tissues. Instead, the undifferentiated mesophyll is similar to spongy tissue. It consists of large isodiametric cells which appear oval or rounded in a transverse section. The mesophyll cells enclose intercellular spaces which are, however, smaller than those of the typical spongy parenchyma. The intercellular spaces form an aerating system which communicates with the stomata through substomatal cavities.

The mesophyll cells are chlorenchymatous and contain a number of chloroplasts. Therefore, mesophyll constitutes the photosynthetic tissue of the leaf.

Differences between Dicot (Dorsiventral) and Monocot (Isobilateral) Leaves

Dicot (Dorsiventral) Leaf	*Monocot (Isobilateral) Leaf*
1. The upper surface is dark green while the lower surface is light green.	1. The two surfaces are equally green.
2. The epidermal cells have sinuous lateral walls.	2. The epidermal cells have almost straight lateral walls.
3. Silica is not normally deposited on the epidermal cells.	3. Silica deposition occurs on the walls of epidermal cells.
4. Stomata are absent or less abundant on the upper side.	4. The stomata are equally distributed on the two sides.
5. The stomata have kidney-shaped guard cells.	5. The stomata have dumb bell-shaped guard cells.
6. The veins do not run parallel. Instead they form reticulations.	6. The veins run parallel to one another.
7. Mesophyll is differentiated into two parts, upper palisade and lower spongy.	7. Mesophyll is undifferentiated.
8. Protoxylem is indistinguishable.	8. Larger vascular bundles may show distinction into protoxylem and metaxylem.
9. Bundle sheath is generally single layered and formed of colourless cells.	9. Bundle sheath may be single or double layered. The cells generally possess chloroplasts.
10. Bundle sheath extensions are parenchymatous.	10. Bundle sheath extensions are sclerenchymatous.
11. Hypodermis of the midrib region is collenchymatous.	11. Hypodermis of the midrib region is sclerenchymatous.

3. **Vascular System.** A large number of closely placed small and a few large vascular bundles run parallel to one another in the mesophyll. Each vascular bundle is surrounded by a single sheath of compactly arranged parenchyma cells called **border parenchyma** or **bundle sheath**. It is chlorenchymatous. The cereals with a single bundle sheath are called **panicoid** grasses. Double

bundle sheath occurs in *Triticum* (Wheat) and some other cereals. They are called **festucoid grasses**. Larger vascular bundles bear **bundle sheath extensions**. The extensions are sclerenchymatous and provide mechanical strength to the leaf.

The vascular bundles are conjoint, collateral and closed. Phloem lies towards the lower side while xylem is found towards the upper side. Phloem consists of sieve tubes and companion cells. Xylem is formed of vessels, tracheids and xylem parenchyma. In small vascular bundles the xylem is compact. In larger vascular bundles xylem is similar to that of stem— with two large, pitted, oval and lateral metaxylem vessels connected by tracheids and smaller spiral or annular oval protoxylem vessels towards the upper side where a **protoxylem lacuna** or **cavity** is also present. Protoxylem being present on the upper or inner side, xylem is endarch.

In Maize leaf the undifferentiated mesophyll occurs in concentric layers around vascular bundles having large centrifugal chloroplasts in its large bundle sheath cells. Such an arrangement is called **Kranz anatomy**.

4. **Midrib**. It is the thickest part of the leaf. Midrib is represented by a shallow groove on the upper surface and a broad ridge on the lower surface. The wide midrib does not contain any mesophyll. Sclerenchyma occurs in patches inner to both the upper and lower epidermis. A number of parallel running vascular bundles are embedded partially in the sclerenchyma found towards the lower side. The remaining ground tissue is made up of nongreen parenchyma.

Other Leaf Types

Multilayered epidermis is found in a few leaves like *Ficus, Begonia* and *Nerium.* In xerophytic leaves, spongy parenchyma is reduced. Palisade parenchyma may occur on both upper and lower sides with spongy parenchyma sandwitched between the two, *e.g., Nerium.* In *Nerium* or Oleander, the lower surface bears deep depressions called **crypts** (stomatal crypts). The crypts possess a number of cutinised hair and stomata. In other xerophytic plants, stomata occur individually and are **sunken** below the surface due to their being overtopped by accessory or subsidiary cells.

Floating leaves possess stomata on the upper surface (epistomatic) only, *e.g., Nymphea.* Submerged hydrophytic leaves do not have stomata (*e.g., Hydrilla, Potamogeton*). The leaves are covered by mucilage. Internally, they have thin undifferentiated mesophyll. Mechanical tissue is absent. Aerenchyma is present. Xylem is reduced. It may be replaced by a cavity.

Importance of Secondary Growth

1. It is a means of replacement of old non-functional tissues with new active tissues.
2. The plants showing secondary growth can grow and live longer as compared to other plants.
3. It provides a fire proof, insect proof and insulating cover around the older plant parts.
4. Commercial cork is a product of secondary growth. It is obtained from Quercus suber (Cork Oak).
5. Wood is a very important product of secondary growth. It represents secondary xylem.

WOOD AS RAW MATERIAL

Wood or secondary xylem is a renewable natural resource which can last indefinitely provided its use does not exceed its output. Wooden logs constitute **lumber**. Lumber put to use in carpentery is called **timber**. Wood has been in use for house building, furniture, boat building, poles, bridges, toys, carts, musical instruments and implements since the dawn of civilisation, *e.g.,* Indus Valley Civilisation. It is extensively used in sports goods, railway sleepers, coaches,

bodies of trucks, boxes, packing cases, match sticks, plywood, etc. Wood is a unique and important raw material because of the following reasons :

1. Wood can be transported to long distances through rivers without any expenditure. Being light in weight, its transport charges are also low.

2. It is a poor conductor of heat.

3. Wood does not conduct much sound.

4. Dry wood does not allow passage of electricity. However, wet wood does conduct the same.

5. Wooden buildings are warm in winter. They are cool in summer.

6. Unlike metals, changes in temperature do no cause changes in volume of wood.

7. Wood is able to absorb vibrations and shocks. It was, therefore, used in railway sleepers.

8. Wood is very easy to work with even by an untrained person. Many household articles, simple tools and implements are prepared from wood even by ordinary persons.

9. Wood can be cut, peeled, smoothened and joined by glue, nails, screws or bolts. As a result many articles are prepared of wood. They include a vast spectrum from drawing board, packing cases, pencils, hockey or billiard sticks to truck bodies, boats and ships.

10. A cut wood often possesses beautiful designs.

11. Because of its porous nature, wood can hold paint, lacquer, varnish and other types of polishing materials.

12. Wooden articles maintain their shape indefinitely.

13. Wood does not break or split even when it is cut into thin pieces.

14. It can tolerate compression, pull, bending and stearing.

15. Most of furniture is made of wood.

16. It does not develop rusty spots or show signs of crystallisation. Treatment with special chemicals can increase its durability.

17. Wood, which cannot be put to commercial use, is employed as fuel. There is possibility of obtaining motor fuel and several chemicals from wood when fossil fuel would become scarce.

18. Wood is delignified and changed to pulp for manufacture of paper, transparent film, rayon, linoleum, plastics, etc.

Limitations of Wood

1. Wood catches fire when heated to 275°C. It is, therefore, combustible.

2. There is a lot of wastage when wood is used for developing timber articles.

3. Wood cannot be rolled. Therefore, it has to be cut into pieces and the latter nailed or glued to give the required shape. It takes a lot of time.

4. Physical and mechanical properties of wood cannot be improved to any appreciable extent.

5. It is liable to be attacked by termites and micro-organisms of decay.

6. Wood swells up and warps on becoming wet.

ADDITIONAL INFORMATION

- **N. Grew** (1682). Father of Plant Anatomy. Gave the terms of tissue and parenchyma.
- **Nageli** (1858). Gave the terms of meristem, xylem and phloem.
- **Hartig** (1837). Discovered sieve tubes.
- **Mettenius** (1805). Discovered and gave the term of sclerenchyma.
- **Schleiden** (1839). Discovered and gave the term collenchyma.
- **Sanio** (1863). Discovered and gave the

term tracheid.

- Tschirch (1889). Gave the term sclereid and described its types.
- **Angiosperms without Vessels**. Families Winteraceae, Tetracentraceae and Trochodendraceae. Wood without vessels is **homoxylous** while the one with vessels is **heteroxylous**.
- **Gymnosperms with Vessels**. Members of group gnetales.
- **Pteridophytes with Vessels**. Occasional in species of *Selaginella, Dryopteris, Marsilea*, etc.
- **Endodermoid**. The term is used by some authors for endodermis or starch sheath of young stems because of the absence of casparian strips.
- **Leaf Primordium**. Develops from a lateral protrusion or leaf buttress. It grows initially by an apical meristem (permanent in ferns) and then by intercalary meristem.
- Leaf consists of only primary tissues. Secondary growth is limited to wound healing.
- **Cavities**. Of three types: (i) **Schizogenous**. By enlargement of intercellular spaces or separation of cells, *e.g.*, oil duct of Sunflower. (ii) **Lysigenous**. By degeneration of cells, *e.g.* oil cavity of *Citrus*. (iii) **Schizolysigenous**. Partly by separation and partly by degeneration of cells, *e.g.*, protoxylem cavity in Maize stem (Protoxylem or water cavity of Maize stem was formely called lysigenous cavity).
- **Knot**. Wound or base of a fallen branch covered by growth of secondary tissues around it.
- **Abscission**. It involves formation of a special parenchymatous layer called **abscission** or **separation** layer at the base of organ and a layer of suberised thick-walled 'cork' cells called **protective layer** over the mother axis. Degeneration of cells of abscission or separation layer causes abscission.
- **Heartwood**. Most abundant in Mulberry but absent in Poplar and Willow.
- **Most Durable Soft Wood**. *Cedrus deodara*.
- **Most Durable Wood**. Teak (*Tectona grandis*).
- **Lightest Wood**. *Ochroma pyramidale* (= *O. lagopus*).
- **Heaviest Wood**. *Guaiacum officinale*. In India *Acacia sundra*..

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. State the location and functions of different types of meristems.

✓ On the basis of location, meristems are of three types — apical, intercalary and lateral.

(i) **Apical**. It is present at the apices of stem, root and their branches.
Functionas. (i) Growth in length (ii) Formation of primary tissues.

(ii) **Intercalary**. It is found above or below stem nodes and leaf bases.
Functions. (i) Growth of internodes. (ii) Growth in leaves. (iii) Correction of position in lodged stems.

(iii) **Lateral**. (a) **Phellogen** (Cork cambium). It develops from hypodermis in stems and pericycle in roots. **Function**. Formation of protective cork (phellem) and aerating lenticles on the outside and secondary cortex (phelloderm) on the inner side. (b) **Vascular Cambium**. In stem from intrafascicular cambial strips and interfascicular strips. In root from conjuctive parenchyma and pericycle. **Function**. Formation of secondary phloem on outside and secondary xylem on inner side. Vascular rays are formed at intervals for radial conduction.

2. Cork cambium forms tissues that form the cork. Do you agree with this statement. Explain.

✓ **Yes**. Cork combium or **phellogen** is a secondary meristem that develops from pericycle of root and hypodermal layer of stem. Its cells show bipolar divisions, *i.e.*, divisions both on the outerside and inner side. The tissue formed on the outer side is initially living and parenchymatous. Soon its walls become suberised. Living protoplasm dies. The empty cells get filled with tannins, alkaloids and air. The dead suberised tissue is called **cork** or **phellen**.

3. Explain the process of secondary growth in stems of wood angiosperms with the help of schematic diagrams. What is its significance ?

✓ Secondary growth of a woody angiosperm stem occurs by two types of cambia, vascular cambium and cork cambium.

Vascular Cambium. It is formed partly by primary intrafassicular cambial strips and partly by secondary interfascicular strips from medullary rays. Cells of vascular cambium divide both on the outerside as well as on the inner side. Vascular cambial cells called **fusiform initials** form **secondary pholem** on the outer side and **secondary xylem** on the inner side. At places vascular cambium

possesses **ray initials**. They form **vascular rays** (or secondary medullary rays), **pholem rays** in secondary pholem and **wood rays** in secondary xylem.

Secondary pholem or **bast** forms a narrow circle on the outside. As new secondary pholem becomes functional, the previous older pholem gets crushed. Secondary xylem or wood persists. As a result wood grows with age. In order to accomodate it the vascular cambium also grows in diameter by addition of new cells. The phenomenon is called **dilation**.

The yearly growth of wood is distinct in temperate areas. It is called **annual ring**. In each annual ring there is wide **spring** or **early wood** of broader light coloured elements and a narrow **autumn** or **late wood** of narrow dark coloured elements. In old stem, the central part of wood becomes nonfunctional and dark coloured due to tyloses and deposit of resins, gums, tannins. It is called **duromen** or **heart wood**. The outer functional wood is called **sapwood** or **alburnum**.

Cork cambium (Phellogen). It produces secondary growth tissues collectively called **periderm**. Cork cambium develops secondarily from a subepidermal layer of living cells. It produces **phellem** or **cork** on the outside and secondary cortex or **phelloderm** on the inner side. Cork consists of dead, suberised and impermeable cells. At places aerating pores called **lenticels** occur. A lenticel has loosely arranged suberised **complementary cells**. The interspaces help in gaseous exchange. (Refer to Fig. No. 6.29 A, C and D)

Significance of Secondary Growth. Refer to the text.

4. Draw illustrations to bring out anatomical differences between (a) Monocot root and dicot root (b) Monocot stem and dicot stem.

✓ (a) Draw Fig. 6.22 and Fig. 6.23 and **mark**. (i) Wider cortex in monocot root, (ii) Larger number of vascular bundles in monocot root (iii) Presence of pith in monocot root (iv) Rounded vessels in monocot root and polygonal in dicot root.

(b) Draw Fig. 6.27 B and 6.28 B and **mark**. (i) Presence of multicellular hair in dicot and their absence in monocot stem. (ii) Occurrence of collenchymatous hypodermis in dicot stem and sclerenchymatous hypodermis in monocot stem. (iii) Differentiation of cortex, endodermis, pericycle and pith in dicot stem and undifferentiated ground tissue in monocot stem. (iv) Vascular bundles in a ring in dicot stem and scattered in monocot stem. (v) Vascular bundles are open in dicot stem and closed in monocot stem. (vi) A sclerenchymatous sheath and an internal cavity (protoxylem or schizolysigenous cavity) present in vascular bundles of monocots but absent in dicots. (vii) Vessels are polygonal in dicot stem and rounded in monocot stem.

5. Cut a transverse section of young stem of a plant from your school garden and observe it under the microscope. How would you ascertain whether it is monocot stem or dicot stem ? Give reasons.

✓ The section is of dicot stem if it has concentric arrangement of ground tissues, open vascular bundles arranged in a ring and polygonal vessels. It is of monocot stem if the ground tissue is undifferentiated, vascular bundles are closed and scattered, each with a sclerenchymatous sheath, protoxylem cavity and rounded vessels.

7. Why are xylem and pholem called complex tissues ?

✓ A complex tissue is the one which contains two or more than two types of cells which have a common origin and coordinate to perform a common function. Both xylem and pholem are complex tissues. **Xylem** is formed of four types of cells – tracheids, vessles, xylem parenchyma and xylem fibres. All of them coordinate to help in conduction of sap.

Pholem is formed by four types of cells – sieve tubes, companion cells, pholem parenchyma and pholem fibres. They coordinate to conduct food.

8. What is stomatal apparatus ? Explain the structure of stomata with a labelled diagram.

✓ Stomatal apparatus is a pair of guard cells with or without surrounding subsidiary cells which function as a value to open or close a stomatal pore for gaseous exchange and transpiration.

The gurad cells are reniform in most of the plants. They are dumb-bell-shaped in grasses. The guard cells contain chloroplasts and small vacuoles. They are thick-walled in the area of contact and thin-walled elsewhere. As the gurad cells swell up due to endosmosis their thin-walled sides expand. The thick walls of the two gurad cells also bend outwardly and create a pore in between them. Fig 6.16.

9. Name the three basic tissue systems in the flowering plants. Give the tissue names under each system.

✓ The three basic tissue systems are epidermal, ground and vascular.

Epidermal Tissue System. Epidermis and epidermal appendages. Epidermis consists of epidermal cells and guard cells. Epidermal appendages include root hairs, stem hairs, stinging hairs, glandular hairs and emergences.

Ground Tissue System. Hypodermis, cortex, endodermis, pericycle, pith and medullary rays.

Vascular Tissue System. Vascular bundles. They can have pholem, xylem and vascular cambium.

10. What is periderm ? How does periderm formation takes place in the dicot stem ?
✓ **Periderm** is a component of secondary growth that is formed towards the surface of stems and roots, having phellem, phellogen and phelloderm.
Phellogen or **Cork cambium** develops in a subepidermal layer in stem and from pericycle in roots. Its cells undergo bipolar divisions. The cells formed on the outer side undergo suberisation, deposition of tannins and death of cellular contents. The outer tissue of dead suberised cells is called **cork** or **phellem**. At places it conains **lenticels** or aerating pores having loosely arranged suberised complementary cells.
Cells formed by phellogen on the inner side constitute secondary cortex or phelloderm.
11. How is the study of plant anatomy useful to us ?
✓ Refer to the text.
12. Describe the internal structure of a dorsiventral leaf with the help of labelled diagrams.
✓ Refer to the text. Fig. 6.36.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Which industry depends on the knowledge of wood anatomy ?
✓ Plywood industry
2. Which meristem does produce growth in length ?
✓ Primary meristem.
3. What is conjunctive tissue ?
✓ It is a narrow strip of tissue (parenchymatous or sclerenchymatous) that lies between xylem and phloem bundles of root.
4. Name the most durable wood ?
✓ Teak (*Tectona grandis*).
5. What forms the cambial ring in a dicot stem during the secondary growth ?
✓ Fascicular and interfascicular strips of meristem.
6. When do you refer to a vascular bundle as a closed bundle ?
✓ The vascular bundles that lack cambium are called closed bundles, *e.g.*, in monocot stems.
7. From where does the lateral root originate ?
✓ Pericycle of mature zone.
8. What makes the apical meristem of the root sub-terminal ?
✓ Presence of protective root cap.

One Mark Questions (Without Answers)

9. Give suitable terms for : (i) Strip of annual wood formed during period favourable for growth of the plant (ii) Upper surface of the leaf.
10. There are two unlabelled microscopic slides showing transverse sections of root and stem of a dicot plant. How will you differentiate between the two on the basis of the arrangement of the conducting tissue ?
11. Name two types of sieve elements found in phloem.
12. Name the anatomical layer in the root from which the lateral branch of root arises.
13. What is palisade parenchyma ?
14. Name the components of secondary xylem.
15. Define bicollateral vascular bundle.
16. Define collateral vascular bundle.
17. Differentiate fusiform initials and ray initials.
18. Which tissue of the leaf contains chloroplasts ?
19. Define meristems.
20. Why is cambium considered to be a lateral meristem ?
21. Name the type of plant tissue that has characteristically thin-walled cells and retains the capacity of division even at maturity.
22. What is an annual ring ?
23. Name the tissue represented by the jute fibres used for making the ropes.

Two Mark Questions (Without Answers)

24. Distinguish between (a) Tracheid and vessel (b) Sieve cell and sieve tube member (c) Phellem and phelloderm (d) Fascicular cambium and interfascicular cambium (e) Softwood and hardwood.

25. Cork cambium forms tissues that form the cork. Do you agree with this statement ? Explain.
26. Cut a transverse section of young stem of a plant from your school garden and abserve it under the microscope. How would you ascertain whether it is monocot stem or dicot stem. Give reasons.
27. What is the difference between fibres and sclereids in plant histology. Give one example of each.
28. What are the general characteristics of sclerenchyma tissue ? Which type of cells of this tissue are the cause of grittiness of the pulp of pear ?
29. Name the main components of xylem. Which of these is suitable for carrying water ?
30. What are medullary rays and what are their functions ?
31. How open vascular bundles differ from closed vascular bundles ?
32. Distinguish between vessels and sieve tubes.
33. Give any four differences between tracheids and vessels.

Three Mark Questions (Short Answer Type)

34. Why a large number of stomata are present at the lower surface of the dicotyledonous leaves in the terrestrial plants?
35. Mention two differences in the vascular bundles of sunflower and maize stems.
36. What are the differences between the root hairs and stem hairs?
37. Where are the companion cells located in flowering plants ? What is their function ?
38. Name the main components of xylem. Which of these is most suitable for carrying water ?
39. Differentiate between Root apex and shoot apex.
40. Answer the following with reference to the anatomy of dicot root.
(i) Where is pericycle located ? (ii) How are the xylem vessels arranged ? (iii) What do you call such an arrangement ? Which type of cells constitute the cortex ?
41. A T.S. of a trunk of a tree shows concentric rings which are known as growth rings. How are these rings formed ?
42. Give at least two functions of the following : (a) Parenchyma (b) Periderm.
43. What is collenchyma? Explain its structure and function in plant body of a herbaceous angiosperm?

Five Mark Questions (Long Answer Type)

44. Describe the structure and organisation of stem apex.
45. Write a note on parenchyma.
46. Sketch the elements of (a) Xylem and (b) Phloem.
47. Name and define the different types of vascular bundles.
48. Briefly describe the anatomy of primary dicot root.
49. Discuss the internal structure of monocot roots.
50. With the help of diagrams, depict secondary growth in dicot roots.
51. What is xylem ? Explain the structure of various kinds of components of xylem.
52. (a) Differentiate between structure of vascular bundle of a dicot stem and a monocot root.
(b) Draw a labelled diagram of vascular bundle of a monocot stem.
53. Draw a labelled diagram of T.S. of dicot root. Give four differences between internal structure of dicot and monocot root.
54. Draw a well labelled diagram of a typical dicot stem.

Multiple Choice Questions

(1) Axillary and terminal buds developed by activity of (a) lateral meristem (b) intercalary meristem (c) apical meristem (d) parenchyma. *(CBSE 2002)*

(2) Stem of gasses and related plants elongate by the activity of (a) lateral meristem (b) apical mersitem (c) both apical and intercalary meristem (d) intercalary meristem. *(Karnataka 2003)*

(3) Selereids belong to (a) collenchyma (b) xylem (c) sclerenchyma (d) sclerenchyma fibres.(BV 2003)

(4) Separate xylem and phloem bundles are known as (a) radial (b) amphivasal (c) collateral (d) bicollateral.

(5) Motor cells take part in (a) guttation (b) transpiration (c) inrolling (d) all the above. (Manipal 2003)

(6) Vascular bundles are closed when they (a) have cambium (b) lack cambium (c) lack pericycle (d) lack endodermis. *(Orissa 2004)*

(7) Jute fibres deteriorate because they have (a) high cellulose (b) low cellulose (c) high lignin (d) low lignin. *(Orissa 2004)*

(8) Tyloses are balloon-like ingrowths in vessels developing from (a) parenchyma through pits of vessel

wall (b) parenchyma through general surface of vessel wall (c) fibres through general surface of vessel wall (d) fibres through pits on vessel wall. (Pb PMT 2005)

(9) Casparian thickenings occur in the cells of (a) pericycle of stem (b) endodermis of stem (c) pericycle of root (d) endodermis of root. (KCET 2006)

(10) Vascular cambium forms (a) primary xylem and primary phloem (b) secondary xylem and secondary phloem (c) secondary xylem only (d) secondary phloem only. (RPMT 2006)

(11) Lacunate collenchyma occurs in stem of (a) *Leucas* (b) *Cucurbita* (c) Sunflower (d) *Sambucus*. (JKCMEE 2007)

(12) Thin-walled passage cells occur in (a) pholem elements as entry points (b) testa for emergence of embryonal axis (c) central area of style for passage of pollen tube (d) endodermis of root for quick transport of water from cortex to pericycle. (CBSE 2007)

(13) In angiosperms, vascular tissues develop from (a) Phellogen (b) Dermatogen (c) Plerome (d) Periblem. (CBSE 2008)

(14) In sugarcane, length of internodes is variable due to (a) intercalary meristem (b) shoot apical meristem (c) size of lamina of lower node (d) position of axillary buds. (CBSE 2008)

(15) Annular and spirally thickened conducting elements generally develop in protoxylem when root or stem is (a) widening (b) differentiating (c) maturing (d) elongating. (CBSE 2009)

(16) In Barley stem, vascular bundles are (a) open and scattered (b) closed ad scattered (c) closed and radial (d) open and in a ring. (CBSE 2009)

(17) Quiescent centre is found in plant at (a) root tip (b) shoot tip (c) cambium (d) leaf tip. (WB 2010)

(18) Closed vascular bundles are the ones which (a) contain cambium (b) lack cambium (c) lack xylem (d) possess lysigenous cavity. (AFMC 2010)

(19) An old trunk of *Dalbergia* tree would have maximum amount of (a) Primary phloem (b) primary xylem (c) secondary xylem (d) secondary cortex. (RPMT 2011)

(20) Ground tissue consists of (a) Epidermis and cortex (b) All tissues internal to endodermis (c) All tissues external to endodermis (d) All tissues except epidermis and vascular tissues. (AMU 2011)

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the A and R statements, mark the correct answer as

(a) If both A and R are true and R is correct explanation of A

(b) If both A and R are true and R is not correct explanation of A

(c) If A is true and R is false (d) If A and R are false.

1. **Assertion.** Vascular cambium is considered as lateral. (AIIMS 2000)
   Reason. It gives rise to lateral shoots.
   A B C D

2. **Assertion.** In collateral bundles, pholem is situated towards inner side. (AIIMS 2008)
   Reason. In monocot stem, cambium is present.
   A B C D

ANSWERS

Multiple Choice Questions

(1) —c (2) —c (3) —c (4) —a (5) —c (6) —b (7) —c (8) —a (9) —d (10) —b
(11) —b (12) —d (13) —c (14) —a (15) —d (16) —b (17) —a (18) —b (19) —c (20) —d

Assertion and Reason Type Questions

(1) —C (2) —d